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Seismic Behaviour of Asymmetric RC Structures Using NBC 105:2020

Suraj Khadka

M.Tech. Scholar, Department of Civil Engineering, RIMT University, Mandi Gobindgarh, Punjab, India

Correspondence should be addressed to Suraj Khadka ; surajkhadka.mkt@gmail.com

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ABSTRACT- Since, today it is not possible to design the structure with regular shape, my thought is that vertical and/or perpendicular irregularity shall possibly evolve. Failure of structures under dynamic loading is due to these irregularities, which are made responsible for the failure. Recent earthquakes and history indicate that plan asymmetric structures are very prone to being damaged by earthquakes-frequency, due to combination torsional and translational stuff. Consequently, seismic behavior of such structures in the seismic active regions is needed to minimize the intrinsic seismic damages. This thesis attempted to study the torsionality of reinforced concrete structures of plan asymmetry subjected to the effect of earthquake with torsional stuff parameters and at the same time provide a possible outcome for torsional influences. Regular reference and C- C shaped plan asymmetric 10 floor structures, three dimensional finite element models are prepared for the study and analysis is carried out using modal response spectrum system as per NBC 105(2020) in ETABS 2016. The results indicate that plan asymmetric structures are more prone than their normal ones. In order to analyze the model, a response spectrum system is used in ETABS software. The final seismic behaviour of the structures, such as, base shear, storey shear, member forces, overturning moments, displacements, stiffness and cross storey drifts are finally compared.

KEYWORDS- Seismic Behaviour, RC Structures, Asymmetric RC Structures, NBC

I. INTRODUCTION

A "regular" structure is largely an idealized concept, as real-world buildings often exhibit significant variations in mass, stiffness, and strength across their height or plan. Modern multi-story structures frequently incorporate complex geometries and structural systems due to advancements in construction techniques and architectural innovation. Furthermore, inherent irregularities arise from practical constraints such as space limitations, functional requirements, or the implementation of diverse architectural designs. Post-earthquake analyses of structural failures reveal that asymmetric buildings are particularly vulnerable during seismic events. Modern asymmetric structures often feature intricate lateral load-resisting systems, but their complexity can create weak points.

When subjected to lateral forces (e.g., wind or earthquakes), damage typically originates at these structural weak zones. Such vulnerabilities stem from irregularities in stiffness, mass distribution, or load-bearing capacity, which accelerate progressive deterioration and may lead to collapse. For a structure to be truly symmetric, its center of mass and center of stiffness must align along a shared vertical axis at every floor level—a condition rarely met in practice. Most buildings exhibit some degree of asymmetry in plan, elevation, or member configuration, as well as uneven floor mass distribution. Building codes categorize structural irregularities into plan (horizontal) and elevation (vertical) types, though real-world structures often combine both. Vertical irregularities involve disparities in mass, stiffness, or geometry along a building's height, while plan irregularities refer to asymmetries in horizontal layouts. These deviations compromise load transfer efficiency, heightening seismic risk even in technologically advanced designs.

A. Objectives of the study

The main goal of this research is to dissect multistorey R.C. structure models with symmetric and asymmetric plans using the Nepal Building Code(NBC105:2020). The research objectives are:

- To model G 9 structure with a symmetric and asymmetric plan using ETABS.
- To dissect the models by Response SpectrumMethod and compare the values. iii. To make notable observances from the products of analysis(storey shears, drifts, displacements, storey stiffness, reinforcements) it can be used to understand in detail the shear wall actions of the structure in each and every one of the shear wall and without shear wall.
- To review the result and hence decide the conclusions and argue on the results attained.

B. Scope & Limitation of the Study

Following are the scope and limitations of the study of this research:

- ETABS is used to model and analyze buildings with symmetric and asymmetric plans.
- The thesis is restricted to studying behaviour or buildings in seismic zoning factor 0.4
- The beam and column sizes are kept consistent across all models in the study.
- Cross cross-sectional area of both columns is taken the same.

- The effect of earth pressure is not considered during seismic analysis.

II. LITERATURE REVIEW

Madhekar et al. [1] highlighted how translational-torsional coupling significantly increases lateral displacements and internal forces, especially in peripheral columns. They underscored the necessity for specialized design measures to mitigate the risk of collapse in asymmetric multi-storey structures.

A parametric comparison between symmetric and asymmetric buildings under seismic excitation was conducted by S. Arumugham et al.[2]. Using time history analysis, their study demonstrated that the selection of appropriate seismic resistance factors is essential in ensuring structural resilience, especially in earthquake-prone areas.

D. K. Rouniyar et al.[3] explored the impact of mass asymmetry in base-isolated and fixed-base buildings through both response spectrum and non-linear time history analysis using SAP2000. Their findings indicated that mass eccentricity significantly affects the response of both symmetric and asymmetric buildings, especially at higher eccentricity levels (5% to 20%).

In another study, C. G. Karayannis et al. [4] investigated torsional effects in asymmetrical structures under the IS 1893 (Part 1: 2002) code. Their comparative analysis of structures with and without torsional design considerations revealed that torsional forces significantly influence reinforcement requirements, thereby impacting structural safety and cost.

S. H. Jeong et al. [5] carried out an experimental study using a shake table to compare the performance of RC models with and without stiffness irregularities. They concluded that dynamic (inelastic) analysis methods provide a more accurate assessment of maximum displacement than static analysis methods, especially when structural discontinuities are present.

In their parametric study, U. Tumbahang and R. Rathore [6] analyzed various plan geometries, including rectangular, observe the various performances between the models and which will have a better performance between the two. In the present study RCC building models having G+9 stories with regular and irregular plan considered for analysis. The analysis of model is done using dynamic method in ETABS software.

The work of S. Bhattarai et al.[7] investigated constructional defects and their influence on the seismic vulnerability of reinforced concrete buildings. Their results showed that structural configuration and constructional form defects significantly influence the seismic demand when both linear and nonlinear analysis methods are used.

Lastly, O. Bhat et al.[8] studied earthquakes cause major structural damage, especially in asymmetric and high-rise buildings, making earthquake-resistant design essential. Seismic performance can be improved using various types of shear walls—RCC, steel plate, and composite—with their effectiveness analyzed using software like STAAD.

M. M. Abd-Alghany [9] studied, the seismic performance of RC buildings with soft storey using finite element method is investigated. The parameters considered in this research include the height of soft storey, irregularity in building plan dimensions, and the location of soft storey along the building height.

III. METHODOLOGY

This study involves a comparative structural analysis of two reinforced concrete (RC) building models using ETABS 2016 software. The primary objective is to assess the structural response of symmetric and asymmetric buildings under seismic loading conditions.

A. Model Development

Two 10-story building models were developed for the analysis:

- **Model 1**: Symmetric architectural plan with a rectangular footprint of 27.6 m × 27.6 m.
- **Model 2**: Asymmetric plan configuration confined within the same plan area.

Each model consists of three-meter-high floors with a total of ten stories. The foundation depth is taken as 1.6 meters. The cross-sectional dimensions of beams and columns remain constant across all stories to maintain uniformity in design.

B. Load Considerations

- Dead Loads
  The following dead loads were considered:
  - Brick masonry: 20 kN/m³
  - Floor finishes: 1.5 kN/m²
  - Reinforced concrete components: 25 kN/m³
- Live Load
  A uniform live load of 3 kN/m² was applied to all floors except the roof, where it was neglected as per standard design practice.
- Lateral Loads
  Seismic loads were incorporated in accordance with NBC: 105: 2020 using the Equivalent Static Method. The parameters used in the lateral load calculations are as follows:
  Zone Factor (Z): 0.4
- Importance Factor (I): 1.25
- Response Reduction Factor (R): 5 (for SMRF)
- Soil Type: Type A
  The fundamental time period for each model was computed based on modal analysis within ETABS.
- Load Combinations
  The structural models were analyzed using the following load combinations:
  - 1.2 DL + 1.5 LL
  - DL + 0.3 LL ± (0.3 EX ± EY)
  - DL + 0.3 LL ± (EX ± 0.3 EY)

These combinations ensure that both axial and lateral load interactions are accurately represented.

C. Material Properties

The materials used for modeling the structural elements have the following properties:

- **Concrete**: M25 grade for both beams and columns
- **Steel**: Fe 500 grade
- **Modulus of Elasticity of Concrete (Ec)**: 5000√fck N/mm²

- **Modulus of Elasticity of Steel (Es)**: 2×10^5 N/mm^2

D. Structural Element Dimensions

- **Slab thickness**: 125 mm
- **Beams**: 400 mm × 750 mm
- **Columns**: 700 mm × 700 mm
- **Interior walls**: 115 mm
- **Exterior walls**: 230 mm

IV. RESULT AND DISCUSSION

In this study, two reinforced concrete building models (G+9), one with a symmetric plan and the other with an asymmetric plan, were analyzed using the **Response Spectrum Method** as per **NBC 105:2020**. Structural performance parameters including **storey displacement, drift, storey shear, overturning moment, stiffness,** and **base shear** were evaluated in both longitudinal and transverse directions. The results are presented and discussed below.

A. Storey Displacement

The displacement values obtained along both longitudinal and transverse directions demonstrate an increase in displacement with height for both models. However, the **asymmetric model (Model 2)** exhibits higher displacements at almost all levels compared to the **symmetric model (Model 1)**. See the table 1.

- **Longitudinal Direction**: The maximum displacement at the 10th storey is 37.22 mm in Model 2 versus 35.91 mm in Model 1.
- **Transverse Direction**: Model 2 again shows a higher displacement (44.10 mm) compared to Model 1 (35.91 mm).

In below table 1 is showing the displacement values for each story for every model taken into consideration in a longitudinal direction.

Table 1: Displacement values for each story

	Displacement in mm	
Storey Level	**Model 1**	**Model 2**
10	35.914	37.222
9	34.969	36.128
8	33.264	34.257
7	30.728	31.548
6	27.421	28.065
5	23.433	23.901
4	18.867	19.169
3	13.847	14
2	8.543	8.576
1	3.35	3.315
0	0	0

This indicates that asymmetry in the building plan contributes to greater lateral displacements, potentially due to irregular distribution of mass and stiffness.

B. Storey Drift

Drift, which indicates the relative displacement between adjacent storeys, follows a similar trend.

In below table 2 is showing the values of drift for different stories for all the models considered along the longitudinal direction

Table 2: Values of drift for different stories

	Drift	
Storey Level	**Model 1**	**Model 2**
10	0.00033	0.000375
9	0.00059	0.000644
8	0.000869	0.000926
7	0.001123	0.001182
6	0.001346	0.001404
5	0.001533	0.001588
4	0.001679	0.001729
3	0.001771	0.00181
2	0.001739	0.001754
1	0.001117	0.001105
0	0	0

- In both directions, **Model 2 displays consistently higher drift values**, especially noticeable in the mid-height storeys where the drift peaks. See the above table 2.
- **Transverse Direction**: Peak drift in Model 2 reaches **0.002076** at the 3rd storey, while in Model 1 it is **0.001771**. See the above table 2.

This highlights the increased vulnerability of asymmetrical structures to inter-storey deformation under seismic loading, which can have implications for non-structural damage and occupant comfort.

C. Storey Shear

The storey shear values increase progressively from the top storey to the base.

In both directions, **Model 2 experiences higher storey shear forces** at all levels. For instance, the base shear reaches **4035.45 kN** in Model 2 compared to **3382.52 kN** in Model 1. See the below table 3. It is showing the values of storey shear for different stories for all the models along the longitudinal direction

Table 3: Values of storey shear for different stories

	Storey Shear kN	
Storey Level	**Model 1**	**Model 2**
10	-267.5195	-332.9385
9	-890.5191	-1073.4406
8	-1444.2964	-1731.6648
7	-1928.8516	-2307.611
6	-2344.1847	-2801.2791
5	-2690.2955	-3212.6692
4	-2967.1842	-3541.7813

3	-3174.8508	-3788.6153
2	-3313.2951	-3953.1714
1	-3382.5173	-4035.4494
0	0	0

This further emphasizes the structural demand imposed by the asymmetric configuration, which likely causes uneven force distribution and concentration in certain structural elements.

D. Overturning Moment

Overturning moments increase from the roof to the base and are indicative of the torsional and lateral instability potentials.

- **Model 1 demonstrates higher overturning moments than Model 2** in both directions, with maximum values at the base being **309917.57 kN-m** (Model 1) and **221897.93 kN-m** (Model 2) in the longitudinal direction. See the below table 4.

Table 4: Values of the overturning moment for different stories for all the models along the longitudinal direction

	Overturning moment **kN-m**	
Storey Level	**Model 1**	**Model 2**
10	0	0
9	4523.1191	3215.3478
8	17130.5906	12255.9907
7	37003.6053	26514.9328
6	63356.2096	45415.4916
5	95405.9304	68388.0073
4	132315.2542	94826.8123
3	173202.6703	124098.347
2	217118.7019	155523.0964
1	263043.5086	188373.783
0	309917.5702	221897.9272

While Model 1 has higher overturning moments, the relative values must be viewed in the context of its greater lateral stiffness and uniformity in geometry.

V. CONCLUSION

In ETABS software, analysis of response spectrum method for two ten storey building models, one with symmetrical and the other one having an asymmetrical layout is done. Key parameters of storey displacements, storey drift, storey stiffness, time period, base shear and overturning moment are produced by analysis and compared. Conclusions from the analysis results are as follow:

- As the building is 10 storey and asymmetrical layout, it experiences greater displacement than the symmetrical building.
- Although having an asymmetrical layout, the displacement of the 10-storey building is 3.62% higher in the longitudinal direction and 22% higher in the transverse direction compared to the same storey of a symmetrical building. Also, the drift with respect to the longitudinal and transverse direction is 2.22 and 17.22% greater in the building with an asymmetrical plan in comparison the symmetrical layout.

Besides, in longitudinal direction, the overturning moment of the asymmetric plan is reduced by 39.66% compared to that of the symmetric plan, while in transverse direction by 40.22%.

In terms of storey shear, the building with asymmetrical plan exhibits 43.66% reduction in the longitudinal direction and 50.27% reduction in the transverse one as opposed to a building developed with symmetrical plan.

The story stiffness of the asymmetriced plan is much lower than that of the symmetrical plan by 44.16% in the longitudinal direction and 52.83% in the transverse direction.

With regard to base reaction, the reduction in longitudinal and transverse direction of asymmetrical plan over symmetrical plan are recorded as 39.77% and 41.31%, respectively.

By these results, we can infer that seismic performance of the building with symmetrical plan is better than the one with asymmetrical plan. This plan significantly increases the axial forces and torsion in columns, storey shear and floor displacements and makes this plan less suitable for earthquake prone region.

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