



Research Article

Seismic Analysis of Multi-Storied Buildings with Even and Uneven Story Heights Under Symmetric and Unsymmetric Configurations

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Abstract

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Seismic behaviour of 15-storey reinforced-concrete (RCC) frame structures was examined for a variety of configuration geometries. The two buildings included in this study were G + 15 RCC frames: one frame had a symmetrical regular floor plan and equal (even) storey heights, and the other frame had an asymmetrical floor plan or irregular storey heights. The buildings were studied in ETABS 2018 using the response spectrum method, as per IS 1893:2016 (Zone IV, biaxial loading). A comparison of key response characteristics, including total base shear, maximum displacement between storeys, maximum relative displacement between storeys, storey shear and stiffness, and the first-mode period in each direction (X and Y), was conducted. The results indicated that the symmetrical, equal-height model exhibited the most beneficial seismic behaviour. The drift distribution was more even, torsional responses were minimal, and the overall stiffness and strength distribution was more uniform. Previous research has noted that “the perfectly symmetrical layout offers better structural stability because they all share similar stiffnesses and therefore similar load distributions” [2], [3]. Comparison of the symmetrical model data with the unsymmetrical/uneven-height model data revealed that the unsymmetrical/uneven-height model showed poorer earthquake performance. The study found that the irregular case had increases in top-floor displacement of approximately 4–5% and increases in peak storey drift of approximately 12% compared with the regular case. Similar findings have been documented in previous studies, which indicate that irregular buildings experience increased lateral displacement and drift when subjected to lateral forces such as those generated by earthquakes. Building irregularities include vertical irregularities due to a soft or uneven storey. Soft-storey frames tend to generate increased displacements and accelerations when subjected to lateral forces during an earthquake. The asymmetrical/uneven-height model had lower storeys that were significantly softer and experienced larger shear force values than the upper storeys, representing a non-linear distribution of stiffness. Finally, the study determined that the response spectrum method can illustrate the difference in seismic response between the two models and confirm its ability to provide comparative seismic assessments of structures.

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I. INTRODUCTION

Seismic analysis is at the very core of structural engineering as it relates to multi-storey structures, which are generally required to be highly resilient in order to remain structurally safe during earthquakes. Earthquakes represent complex and dynamic processes that are affected by numerous variables, including the geometric form and composition of materials, as well as the integrity of a building's base. In addition to assessing the general behaviour of a building during an earthquake, seismic analysis also studies the influence of various structural configurations, such as symmetric versus unsymmetric and even versus uneven floor height, on the way

a structure responds to seismic forces. Many of the structural irregularities mentioned above can produce undesirable and magnified responses to earthquake-induced loading conditions for a structure. A symmetrical structure with equal floor height is considered the most desirable from a seismic standpoint. This is because the centre of stiffness and the centre of mass align in symmetrical structures; therefore, seismic force is evenly distributed throughout the structure. Due to the uniform distribution of seismic forces within a symmetrical structure, there is less tendency for stress concentrations to occur within specific structural elements and less likelihood of torsion occurring.

II. LITERATURE REVIEW

Seismic behaviour of reinforced cement concrete (RCC) framed buildings is an important topic of investigation in structural engineering, especially in seismic hazard areas. Studies have investigated the influence of building configuration, plan symmetry, and structural irregularity on the seismic behaviour of RCC-framed structures. Nikesh B. Lothe *et al.* [1] assessed the effectiveness of different seismic design approaches to ensure both the safety and longevity of RCC-framed structures during seismic events through the use of the time-history method.

Ishaan Trikha [2] investigated two G + 5-storey RCC-framed buildings with regular rectangular floor plans (symmetrical) and L-shaped floor plans (asymmetrical). The study demonstrated that plan asymmetry enhances lateral seismic response; however, all critical parameters for the G + 5-storey RCC-framed building remained within permissible limits. Nabin Khanal [3] evaluated two G + 4 (ground + four storeys) reinforced cement concrete framed buildings in seismic zone IV, one with a symmetrical design and another with an asymmetrical design. Vikash Sangadiya *et al.* [4] used STAAD Pro to analyse and design a hospital building.

The study reported results for bending moment and displacements. A comparison of the largest displacement and highest storey drift was made among a group of three severely irregularly constructed buildings, including a T-shaped building. The objective of studying seismic demands of regular and irregular RCC buildings using NLTHA was achieved. The impact of base isolators on symmetric and

asymmetric buildings was demonstrated, and structural response was evaluated under dynamic loads using Bhuj earthquake data. Kiran Devi *et al.* [5] studied the effect of the location's seismic zone on base shear force due to an increase in seismic zone from Zone III to Zone V, as the area increases the intensity of the earthquakes. Devi's study examined the comparison of the amount of longitudinal reinforcing steel in a G + 8-storey reinforced concrete structure, the detailing of the reinforcements, and the design base shear force at each seismic zone. The study showed how each of these items is affected by the increasing intensity of earthquakes. Umer Fayaz *et al.* [6] studied a hypothetical G + 5-storey reinforced concrete building under seismic load, wind load, and live load using ETABS.

The study objective was to investigate a multi-storey building loaded by seismic forces. Apurva M. Dhasade *et al.* [7] provided a direct method of supporting the objective of analysing structural performance under seismic loading. The paper compares a conventional structure and a floating column structure, supporting studies that analyse storey displacement, drift, stiffness, member forces, and related parameters. M. T. Raagavi *et al.* [8] showed that the effect of plan irregularities in buildings on seismic behaviour due to the presence of torsion and eccentricities is considerable. Asymmetric structures had the least amount of base shear and displacement but had better load transfer characteristics than symmetric structures, which enhanced their safety. L-shaped structures exhibited the worst performance, especially at upper floors. O-shaped and regular structures experienced higher displacement values, while octagonal structures exhibited lower moment and beam-end forces.

III. MATERIALS AND METHODS

A. Model Development

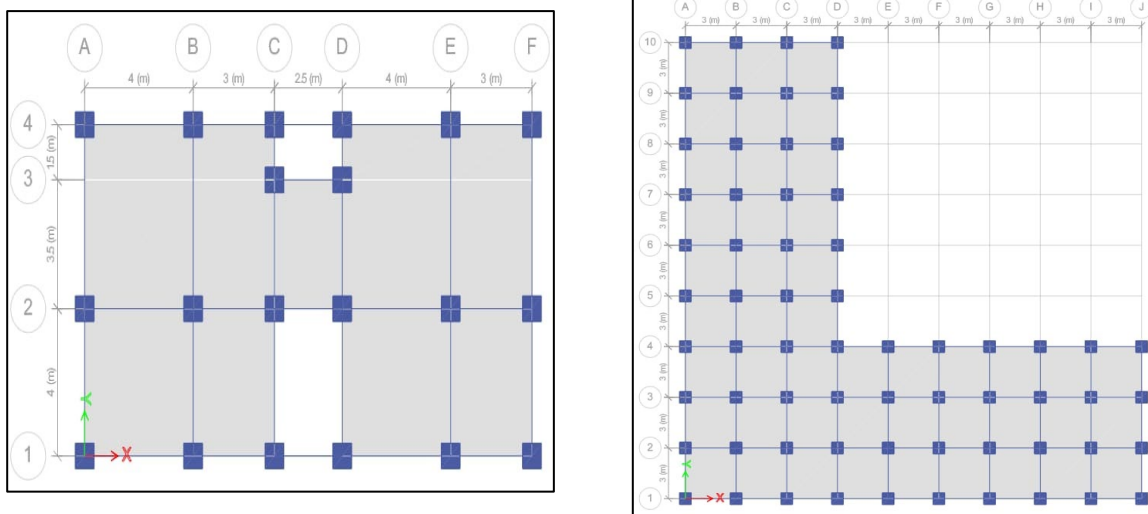


Fig.1 Plan View Showing Column Grid Arrangement for Symmetric (Left) and Asymmetric (Right) RCC Structures

A G + 15-storey RCC framed building model was designed, developed, and analysed using two models in ETABS 2018+.

Model 1

1. Floor height: 3 m
2. Beam size: 300 mm × 690 mm

3. Column size: 690 mm × 690 mm
4. Slab thickness: 125 mm
5. Concrete strength grade: M30
6. Steel strength grade: Fe500

Model 2

1. Floor height: 3.3 m
2. Beam size: 300 mm × 690 mm
3. Column size: 690 mm × 690 mm
4. Slab thickness: 125 mm
5. Concrete strength grade: M30
6. Steel strength grade: Fe500

B. Loading Considerations

1. Applied dead load (DL) and live load (LL), according to IS 875 (Parts 1 and 2).
2. The equivalent static method was used to generate seismic loads in accordance with IS 1893:2016.
3. Zone: IV (factor = 0.24).
4. Importance factor (I): 1.0.
5. Response reduction factor: 5.0 (SMRF).
6. Type of soil: Medium (Type II).
7. Damping: 5%.
8. The seismic forces were applied in both X and Y directions (EQX and EQY).

C. Load Combinations

The load combinations used in this study were identified according to the requirements of IS 1893 and IS 875 (Part 5). As part of the analytical work presented here, all load combinations were considered without taking into account any uncorrected values for the purpose of comparison.

D. Analysis

1. Response spectrum analysis was carried out using ETABS for each model.
2. Since the objective of the present work was limited to the analysis and comparison of results, no design checks were performed.

IV. RESULTS AND DISCUSSION

Linear static seismic analysis in ETABS was used to compare the seismic behaviour of symmetric and asymmetric reinforced concrete structures. The studies were performed based on the response spectrum method as per IS 1893:2016. Four primary response parameters, namely base shear, storey shear, storey drift, and storey displacement due to seismic loading in both X and Y directions (EQX and EQY), were studied to evaluate the seismic behaviour of the symmetric and asymmetric models.

A. Base Shear

Base shear is defined as the total horizontal seismic load that is transferred from the structural system above the foundation during an earthquake. It is an important factor for evaluating the total horizontal forces acting on a structural system.

TABLE I BASE SHEAR VALUES UNDER SYMMETRIC AND UNSYMMETRIC BUILDINGS

Base shear in kN		
Model	EQX	EQY
Model 1	1687.9278	1687.9278
Model 2	4371.7128	4371.7128

B. Storey Displacement

TABLE II STOREY DISPLACEMENT VALUES UNDER SYMMETRIC AND UNSYMMETRIC BUILDINGS

Displacement in mm		
Storey	Model 1	Model 2
15	30.24	31.662
14	29.176	30.562
13	27.955	29.313
12	26.57	27.9
11	25.033	26.329
10	23.36	24.612
9	21.568	22.764
8	19.673	20.802
7	17.693	18.74
6	15.641	16.596
5	13.533	14.384
4	11.384	12.122
3	9.214	9.829
2	7.044	7.525
1	4.905	5.239
Ground	2.848	3.018
Plinth	1.012	1.007
Footing	0	0

Maximum lateral displacement occurred at the top storey level with some variance between the two different models (symmetric and asymmetric), in addition to the differences noted when comparing the longitudinal response spectrum loading. The asymmetric model produced slightly larger lateral displacements than the symmetric model. Top-storey displacement increased by 4.7%, to 31.662 mm compared with 30.24 mm for the symmetric model in this loading case.

C. Storey Drift

Storey drift represents another measure of storey-by-storey deformation resulting from seismic action. As expected,

storey drifts tend to increase with increasing storey height; however, all measured drift values are less than those permitted in IS 1893:2016. Buildings with non-uniform storey heights or unsymmetrical configurations have higher drift requirements than buildings with uniform storey heights and symmetrical configurations. The asymmetry appears most pronounced in the middle of the building, which indicates a greater effect of torsion on storey drift. The drift ratio for the asymmetric configuration is approximately 12.1% larger than that of the symmetric configuration.

TABLE III STOREY DRIFT VALUES UNDER SYMMETRIC AND UNSYMMETRIC BUILDINGS

Storey drift in mm		
Storey	Model 1	Model 2
15	0.00024	0.000346
14	0.000294	0.000399
13	0.000352	0.000456
12	0.000405	0.000509
11	0.000452	0.000555
10	0.000492	0.000595
9	0.000527	0.000627
8	0.000556	0.000653
7	0.00058	0.000673
6	0.0006	0.000688
5	0.000614	0.000699
4	0.000624	0.000704
3	0.000628	0.000703
2	0.000626	0.000695
1	0.000612	0.000674
Ground	0.000568	0.000611
Plinth	0.000336	0.000336
Footing	0	0

D. Storey Shear

The storey shears represent how seismic force is transferred along the height of the buildings. Maximum shear force is experienced by the lowermost floor of the building and

reduces with increasing height. For the unsymmetric models, the distribution of stiffness is uneven; therefore, the unsymmetrical models produce larger shear forces in the lower storeys. This phenomenon occurred consistently through all storeys of each model.

TABLE IV STOREY SHEAR VALUES UNDER SYMMETRIC AND UNSYMMETRIC BUILDINGS

Storey shear in kN		
Storey	Model 1	Model 2
15	168.9757	437.6926
14	366.3729	963.0927
13	541.6589	1424.4725
12	695.1225	1821.6637
11	830.2823	2165.3848
10	950.706	2467.8929
9	1058.6594	2737.8946

8	1156.0319	2981.981
7	1245.2117	3206.8574
6	1328.3471	3417.9873
5	1406.1503	3617.2831
4	1478.0335	3803.9529
3	1543.1581	3976.7374
2	1600.4505	4132.5446
1	1647.2735	4261.9838
Ground	1679.0114	4349.0962
Plinth	1687.9278	4371.7128
Footing	0	0

E. Summary of Findings

Uniformly configured structures with symmetrical configurations perform better under seismic loads than structures that have uneven storey heights and/or unsymmetrical configurations because they distribute seismic force and deformations more uniformly. Structures with uneven storey heights and unsymmetrical configurations experience greater lateral displacements, greater storey drift, and greater torsional effects than structures with uniformly configured and symmetrical configurations. The response spectrum method is effective in representing the modal behaviour of structures and provides a suitable basis for comparing the seismic response of different structural configurations.

V. CONCLUSION

Using ETABS software, the response spectrum methodology and the static analysis approach were investigated for two distinct G + 15 building models. In evaluating the relative merits of each structural configuration analysed, comparisons were made based on key response parameters derived from the analyses. Specifically, the responses included base shear, storey displacement, storey drift, storey stiffness, and fundamental time period. It can be concluded from the data collected that lateral displacement increases progressively from the base of the structure towards the top of the structure in both structural configurations, indicating an approximately linear relationship as observed in static analysis. While plan unsymmetry can influence seismic behaviour, the magnitude of this impact will be relatively small when considering high-rise structures in the context of seismic analysis. As such, it is extremely important to consider structural configuration early in the planning stages of construction, especially for structures sensitive to performance and located in areas subject to high levels of seismic activity.

Declaration of Conflicting Interests

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Use of Artificial Intelligence (AI)-Assisted Technology for Manuscript Preparation

The authors confirm that no AI-assisted technologies were used in the preparation or writing of the manuscript, and no images were altered using AI.

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