

Seismic Behaviour of RC Buildings Constructed on Plain and Sloping Ground with Different Configuration of Shear Wall

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Abstract

The seismic behavior of multi-storey reinforced concrete (RC) buildings is greatly influenced by the nature of the ground topography (whether flat or sloped) and the systems used to resist lateral loads. This study explores a G+17 RC building modelled on both level and sloping terrains, incorporating various shear wall configurations such as core, edge, corner, rectangular, L-shaped, T-shaped, and channel-shaped. Structural modeling and Response Spectrum Analysis are performed using ETABS in accordance with IS 1893:2002 for Seismic Zones III, IV, and V, considering Type II (medium) soil conditions. The materials used include M30 concrete and Fe500 reinforcement. The study evaluates critical response parameters such as storey displacement, storey drift, base shear, floor acceleration, and internal member forces. The analysis reveals that sloped terrains cause significant torsional coupling and increased lateral displacement due to uneven column heights and stiffness asymmetry. On flat terrain, centrally placed rectangular shear walls offer the best lateral stiffness. On sloped terrain, regular rectangular shear wall configurations are more effective than asymmetrical ones (L-, T-, and channel-shaped) in reducing torsional modes and differential drift demands.

Keywords: Seismic Evaluation, Reinforced Concrete Frame Structures, Shear Wall Arrangement, Inclined Terrain, ETABS, Response Spectrum Technique, Storey Displacement, Base Shear Force.

1. Introduction

Earthquakes continue to be among the most devastating natural disasters, exerting dynamic forces that challenge the structural soundness of buildings. The swift urban expansion in hilly and mountainous areas has necessitated the construction of multi-storey reinforced concrete (RC) buildings on sloped terrain. Structures on such inclines display dynamic properties that are inherently different from those on flat ground. Differences in foundation height result in varying column lengths within a single storey. This imbalance causes the center of stiffness to deviate from the center of mass, leading to torsional amplification and stress concentration in the shorter, more rigid columns during seismic events.

To address lateral drift and torsional instability, reinforced concrete shear walls are utilized as efficient systems for resisting lateral loads. These shear walls offer significant in-plane stiffness and strength, safeguarding the gravity load-resisting frame from excessive lateral movements. However, incorrect placement of shear walls—particularly on sloped terrain—can worsen structural eccentricities.

This research models and assesses a G+17 RC building with various shear wall configurations on both flat and sloped landscapes. By employing Response Spectrum Analysis according to IS 1893:2002 across Seismic Zones III, IV, and V, this paper offers quantitative design guidance for tall RC buildings constructed on uneven terrain.

2. Methodology & Structural Modeling

2.1 Building Configuration and Geometry

The structure under examination is a reinforced concrete frame building with 17 floors above the ground level. The building's total length and width are specified as (). Each storey has a standard height of , resulting in a complete structural height of from the base. The foundation conditions vary, encompassing both flat (plain) foundation arrangements and areas with changes in elevation due to sloped terrain.

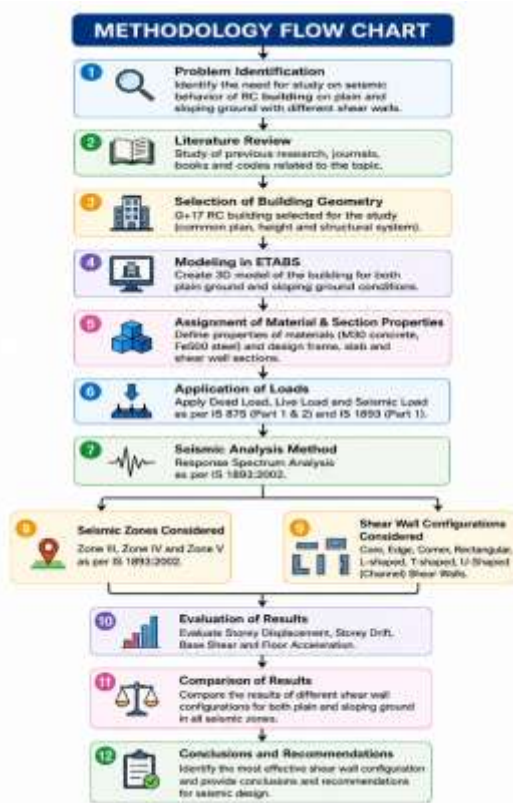


Figure 1: Analytical research methodology framework.

2.2 Material and Section Properties

Concrete grade M30 was designated for the structural components, while Fe500 high-yield strength deformed steel bars were utilized. Tables 1 and 2 provide a comprehensive overview of the fundamental structural specifications and seismic design criteria.

Table 1: Structural Section Details & Design Parameters

Parameter	Value / Property
Building Function	Residential
Storey Configuration	G+17
Total Height (H)	51.5 m
Plan Dimensions	21.0 m $\times$ 17.5 m
Foundation Depth	1.5 m
Columns	900 mm $\times$ 600 mm
Beams	230 mm $\times$ 600 mm
Slab Thickness	150 mm
Concrete Grade	M30 ($f_{ck} = 30$ N/mm ²)
Reinforcement Grade	Fe500 ($f_y = 500$ N/mm ²)
Soil Type	Type II (Medium Soil)

Table 2: Applied Load Cases & Seismic Input Coefficients

Parameter / Load Type	Applied Value / Factor	Code Provision
Dead Load (DL)	Self-weight calculated	IS 875 (Part 1)
Imposed / Live Load (LL)	3.5 kN/m ²	IS 875 (Part 2)
Wall / Member Load	12.0 kN/m	IS 875 (Part 1)
Importance Factor (I)	1.0	IS 1893:2002
Response Reduction Factor (R)	5.0 (SMRF)	IS 1893:2002
Seismic Zone II / III / IV / V (Z)	0.16/0.24 / 0.36	IS 1893:2002

2.3 Load Combinations

Design analyses evaluate limit states using the following combinations as specified by Indian Standards:

1. 1.5(DL + LL)
2. 1.2(DL + LL ± EL)
3. 1.5(DL ± EL)
4. 0.9DL ± 1.5EL

2.4 Response Spectrum Method

Dynamic Response Spectrum Analysis was executed per IS 1893:2002. The elastic design acceleration spectrum value ($\frac{S_a}{g}$) for Type II soil is defined by:

$$\frac{S_a}{g} = \begin{cases} 1 + 15T, & 0.00 \leq T \leq 0.10 \text{ s} \\ 2.50, & 0.10 \leq T \leq 0.55 \text{ s} \\ \frac{1.36}{T}, & 0.55 \leq T \leq 4.00 \text{ s} \end{cases}$$

Where T represents the structural fundamental period. Modal combination was conducted using the Complete Quadratic Combination (CQC) technique to account for closely spaced modes:

$$\lambda_k = \sqrt{\sum_i \sum_j \lambda_i \rho_{ij} \lambda_j}$$

Where ρ_{ij} is the cross-modal correlation coefficient. The design base shear (V_B) calculated via modal superposition was scaled against the equivalent static base shear (V_b) to ensure $V_B \geq V_b$.

3. Dynamic Results & Tabular Analysis

Seismic Zones III, IV, and V have been analyzed using ETABS, and the results have been compiled. The analysis examines storey displacement, storey drift, storey shear, the distribution of lateral loads, and the internal forces within columns and beams.

3.1 Storey Displacement Response

Maximum lateral displacements occur at the roof level (Storey 17) and scale up with the Seismic Zone Factor (Z).

Table 3: Comparative Storey Displacements across Seismic Zones III, IV, and V

Storey	Elevation (m)	Zone III: EQ X (mm)	Zone III: EQ Y (mm)	Zone IV: EQ X (mm)	Zone IV: EQ Y (mm)	Zone V: EQ X (mm)	Zone V: EQ Y (mm)
Story17	51.5	11.8	13.1	17.7	19.6	26.5	29.5
Story16	48.5	11.6	12.8	17.3	19.2	26.0	28.9
Story15	45.5	11.2	12.5	16.9	18.7	25.3	28.1
Story14	42.5	10.8	12.0	16.3	18.1	24.4	27.1
Story13	39.5	10.4	11.5	15.5	17.3	23.3	25.9
Story12	36.5	9.8	10.9	14.7	16.4	22.1	24.5

Story11	33.5	9.2	10.2	13.8	15.3	20.7	23.0
Story10	30.5	8.6	9.5	12.8	14.3	19.3	21.4
Story9	27.5	7.9	8.7	11.8	13.1	17.7	19.7
Story8	24.5	7.1	7.9	10.7	11.9	16.1	17.9
Story7	21.5	6.4	7.1	9.6	10.7	14.4	16.0
Story6	18.5	5.6	6.3	8.5	9.4	12.7	14.1
Story5	15.5	4.9	5.4	7.3	8.2	11.0	12.2
Story4	12.5	4.1	4.6	6.1	6.9	9.2	10.3
Story3	9.5	3.3	3.7	5.0	5.6	7.4	8.4
Story2	6.5	2.5	2.8	3.7	4.2	5.6	6.4
Story1	3.5	1.5	1.8	2.3	2.7	3.5	4.1
Base	0.0	0.0	0.0	0.0	0.0	0.0	0.0

3.2 Inter-Storey Drift Response

Due to the flexibility at the base and the distribution of shear forces, the peak of storey drifts occurs at the lower levels (Storey 1) and then decreases as it moves towards the higher storeys.

Table 4: Storey Drift Profiles across Seismic Zones III, IV, and V

Storey	Elevation (m)	Zone III: EQ X	Zone III: EQ Y	Zone IV: EQ X	Zone IV: EQ Y	Zone V: EQ X	Zone V: EQ Y
Story17	51.5	0.000080	0.000089	0.000120	0.000133	0.000180	0.000200
Story16	48.5	0.000105	0.000117	0.000157	0.000175	0.000236	0.000263
Story15	45.5	0.000133	0.000148	0.000199	0.000222	0.000299	0.000332
Story14	42.5	0.000159	0.000176	0.000238	0.000265	0.000358	0.000397
Story13	39.5	0.000182	0.000202	0.000273	0.000303	0.000409	0.000454
Story12	36.5	0.000202	0.000223	0.000302	0.000335	0.000454	0.000502
Story11	33.5	0.000218	0.000241	0.000327	0.000361	0.000490	0.000542
Story10	30.5	0.000231	0.000255	0.000346	0.000382	0.000519	0.000574
Story9	27.5	0.000241	0.000266	0.000361	0.000399	0.000542	0.000598
Story8	24.5	0.000248	0.000274	0.000373	0.000411	0.000559	0.000616

Story7	21.5	0.000253	0.000279	0.000380	0.000419	0.000570	0.000628
Story6	18.5	0.000257	0.000282	0.000385	0.000423	0.000577	0.000635
Story5	15.5	0.000259	0.000284	0.000388	0.000426	0.000583	0.000639
Story4	12.5	0.000263	0.000287	0.000394	0.000431	0.000591	0.000647
Story3	9.5	0.000275	0.000300	0.000412	0.000450	0.000618	0.000675
Story2	6.5	0.000313	0.000352	0.000470	0.000528	0.000704	0.000792
Story1	3.5	0.000440	0.000515	0.000660	0.000773	0.000990	0.001159
Base	0.0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

3.3 Lateral Force & Storey Shear Distribution

As one moves to higher levels, the lateral seismic forces applied grow in a nonlinear fashion, while the cumulative storey shear is at its peak at the base of the building.

Table 5: Lateral Seismic Forces and Storey Shears across Zones III, IV, and V

Storey	Zone III Force X (kN)	Zone III Shear X (kN)	Zone IV Force X (kN)	Zone IV Shear X (kN)	Zone V Force X (kN)	Zone V Shear X (kN)
Story17	153.29	-153.29	229.93	-229.93	344.89	-344.89
Story16	179.12	-332.41	268.69	-498.61	403.03	-747.92
Story15	157.65	-490.06	236.47	-735.09	354.71	-1102.63
Story14	137.55	-627.60	206.32	-941.40	309.48	-1412.11
Story13	118.81	-746.42	178.22	-1119.62	267.33	-1679.44
Story12	101.45	-847.87	152.18	-1271.80	228.26	-1907.70
Story11	85.46	-933.33	128.19	-1399.99	192.28	-2099.98
Story10	70.84	-1004.16	106.26	-1506.25	159.39	-2259.37
Story9	57.59	-1061.75	86.38	-1592.63	129.57	-2388.94
Story8	45.71	-1107.46	68.56	-1661.19	102.85	-2491.79
Story7	35.20	-1142.66	52.80	-1713.99	79.20	-2570.99
Story6	26.06	-1168.72	39.09	-1753.09	58.64	-2629.63
Story5	18.30	-1187.02	27.44	-1780.53	41.16	-2670.79
Story4	11.90	-1198.92	17.85	-1798.38	26.77	-2697.56
Story3	6.87	-1205.79	10.31	-1808.68	15.46	-2713.03

Story2	3.22	-1209.01	4.83	-1813.51	7.24	-2720.27
Story1	0.97	-1209.98	1.46	-1814.97	2.18	-2722.45

3.4 Support Reactions

Structural stability limits are confirmed by compiling base reactions across combinations of gravity and seismic design.

Table 6: Global Support Reaction Summary

Load Case / Combo	Zone III: FX (kN)	Zone III: FY (kN)	Zone IV: FX (kN)	Zone IV: FY (kN)	Zone V: FX (kN)	Zone V: FY (kN)	Vertical FZ (kN)
Dead Load	0.00	0.00	0.00	0.00	0.00	0.00	125,486.08
Live Load	0.00	0.00	0.00	0.00	0.00	0.00	23,152.50
EQ X	-1209.98	0.00	-1814.97	0.00	-2722.45	0.00	0.00
EQ Y	0.00	-1087.05	0.00	-1630.58	0.00	-2445.87	0.00
1.5(DL+LL)	0.00	0.00	0.00	0.00	0.00	0.00	222,957.87
Max Comb (Zone)	1814.97	-1630.58	2722.45	-2445.87	4083.67	-3668.80	188,229.12

4. Discussion of Findings

4.1 Influence of Seismic Zonation

Seismic demands exhibit a linear relationship with the zone factor. At Storey 17, the maximum displacements due to lateral loads (EQ Y) rise from in Zone III to in Zone IV, and further to in Zone V. Similarly, the peak base shear in the X-direction progresses from in Zone III to in Zone IV, ultimately reaching in Zone V. This incremental increase underscores the necessity for larger member sizes and enhanced shear wall stiffness in regions with high seismic activity, such as Zones IV and V.

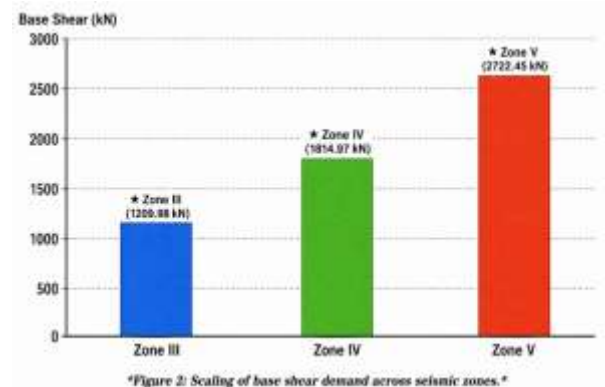


Figure 2: Scaling of base shear demand across seismic zones.

4.2 Topographic Effect: Plain vs. Sloping Ground

Structures situated on inclined land encounter uneven distribution of base shear because of the differing levels of their foundations. Columns that are shorter and positioned on the higher part of the slope exhibit much greater lateral stiffness compared to the longer columns found on the lower part of the slope. This discrepancy results in intense shear stress concentrations in the

shorter columns and leads to the emergence of torsional modes during seismic activity.

4.3 Shear Wall Configuration & Geometry

1. **Plain Ground:** Core shear walls positioned centrally around lift shafts help minimize building torsion by aligning the center of mass with the center of rigidity. When placed at the edges or corners, these walls create localized eccentricity, resulting in slight torsional amplification.
2. **Sloping Ground:** Symmetrically designed standard rectangular shear walls exhibit superior performance compared to asymmetrical configurations such as L-, T-, and channel-shaped walls. The irregular sections of shear walls intensify the mass-stiffness eccentricities caused by differing column heights, leading to intricate coupled lateral-torsional modes.

5. Conclusions

This investigation yields key structural insights for high-rise RC building design:

1. **Dynamic Scaling:** Base shear, lateral force requirements, storey displacement, and inter-storey drift are directly proportional to the seismic zone factor (Z), with an increase of over from Zone III to Zone V.
2. **Sloping Terrain Vulnerability:** On sloped terrain, the difference in column lengths results in uneven stiffness, which directs torsional forces and stress concentrations towards the shorter columns.
3. **Optimal Configuration:** Rectangular shear walls located centrally deliver significant lateral stiffness and reduce torsional drift on flat terrain. On sloped ground, symmetrical placement of regular rectangular shear walls ensures greater stability than asymmetrical L-, T-, or channel-shaped configurations.
4. **Member Force Profile:** In the lower storeys, the variations in maximum bending moments, shear forces, and axial forces are concentrated, necessitating ductile detailing at these structural levels.

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