

Seismic Performance of Multi-Storey Buildings with Diaphragm Discontinuities: A Comparative Study of Different Opening Configurations

Pooja Navnath Lokhande, M. Tech Student, Department of Civil Engineering, DBATU University, Lonere [1]

Dr.G.R. Gandhe, Professor & Head of Department, Department of Civil Engineering, DBATU University, Lonere [2]

Department of Civil Engineering

Deogiri Institute of Engineering & Management Studies, Chhatrapati Sambhajnagar

Abstract

This research examines the seismic performance of high-rise reinforced concrete buildings with diaphragm discontinuities, focusing on the management implications of different floor opening configurations. Using ETABS software, a G+25 storey building was analysed with central, corner, elongated, and H-shaped openings under response spectrum analysis as per IS 1893 (Part 1):2016. Structural response was evaluated in terms of storey displacement, drift, and base shear. Results show that corner openings provide maximum stiffness, attracting higher base shear (100%) but maintaining the lowest drift (28% of centre). In contrast, centre openings reduce seismic demand (base shear ~95%) but increase drift (100%), reflecting flexibility at the cost of serviceability. Elongated and H-shaped openings achieved balanced behaviour between stiffness and flexibility. All cases satisfied IS 1893 drift limits ($\leq 0.004h$ per storey), ensuring code compliance. Beyond structural performance, this study provides insights for construction technology management and risk mitigation, supporting decision-making in selecting optimal floor opening strategies for safe, economical, and resilient high-rise buildings.

Keywords - Seismic performance; Diaphragm discontinuity; Storey drift; Base shear; Risk management; Technology management in construction; Structural innovation

1. Introduction

In the design of multi-storey buildings, diaphragms are critical structural components that transfer lateral loads to vertical resisting elements such as shear walls and frames. The presence of diaphragm discontinuities, caused by openings for services such as elevators, ventilation, and stairs, can significantly affect the seismic response of a structure. Openings alter stiffness, mass distribution, and load transfer paths, potentially resulting in torsional effects and increased displacements. This study investigates the influence of different diaphragm opening configurations—corner, centre, elongated, and H-shaped—on the seismic behaviour of a high-rise

building. The analysis follows the guidelines of IS 1893 (Part 1):2016, using ETABS software to perform Response Spectrum Analysis.

2. Aim

The primary aim of this research is to investigate the seismic performance of multi-storey reinforced concrete buildings with diaphragm discontinuities, focusing on different opening configurations. The study seeks to understand how variations in diaphragm openings influence key seismic parameters such as displacement, drift, and base shear, and to interpret these findings within the context of risk management and construction technology decision-making.

3. Objectives

The objectives of this study are as follows:

- To evaluate the impact of different diaphragm opening configurations on the seismic performance of high-rise buildings.
- To compare structural response parameters such as storey displacement, storey drift, and base shear for various opening types.
- To assess the compliance of each configuration with IS 1893:2016 permissible limits.
- To provide insights into the management implications of diaphragm discontinuities for risk mitigation and construction technology strategies.
- To recommend the most balanced and practical opening configuration for ensuring both structural safety and economical design.

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2. Literature Review

A range of studies have examined diaphragm discontinuities and their impact on seismic response. Godinez et al. (2023) proposed a stringer-panel model for diaphragm analysis, demonstrating the influence of force redistribution after cracking. Kumar et al. (2022) highlighted the efficiency of rigid diaphragms with peripheral shear walls. Gangel (2021) distinguished the seismic design approaches for rigid and flexible diaphragms. Avila et al. (2021) studied CLT hybrid systems, showing varying responses between semi-rigid and flexible behaviour. Other researchers such as Pang et al. (2020), Solarino et al. (2019), Wang et al. (2019), and Loss et al.

(2017) have investigated diaphragm strength, stiffness, and connections in both modern and historical structures. Overall, these studies confirm that diaphragm discontinuities significantly influence seismic performance, emphasizing the need for proper design strategies to maintain safety and serviceability.

3. Methodology

A G+25 reinforced concrete building was modelled in ETABS to study the effect of diaphragm discontinuities. The analysis was performed using Response Spectrum Analysis (RSA) as per IS 1893 (Part 1):2016. Different floor opening configurations—central, corner, elongated, and H-shaped—were considered to evaluate seismic performance in terms of displacement, drift, and base shear. The essential modelling parameters are summarized in Table 1.

No of story	G+25
Plan area	35X35 m ²
Concrete grade	M45
Steel grade	HYSD 500
Size of Beam	B-400mmX750mm
Size of Column	C-500x1000 mm
Each story height	3.5 m
Thickness of Slab	150mm
Thickness of wall	230 mm
Floor finish	2KN/m ²
Live load	2KN/m ² (IS 875 part 2-1987)

Table 1: Building and Analysis Details for Seismic Modelling

Seismic data	Value
zone factor(z)	0.36
Importance Factor	1.2
Response Reduction Factor	5

Table 2: Seismic Parameters Considered for Analysis

4. Results and Discussion

The analysis results are discussed in three main aspects: (i) Storey displacement, (ii) Storey drift, and (iii) Base shear. Results are compared among the four diaphragm opening types.

4.1 Storey Displacement

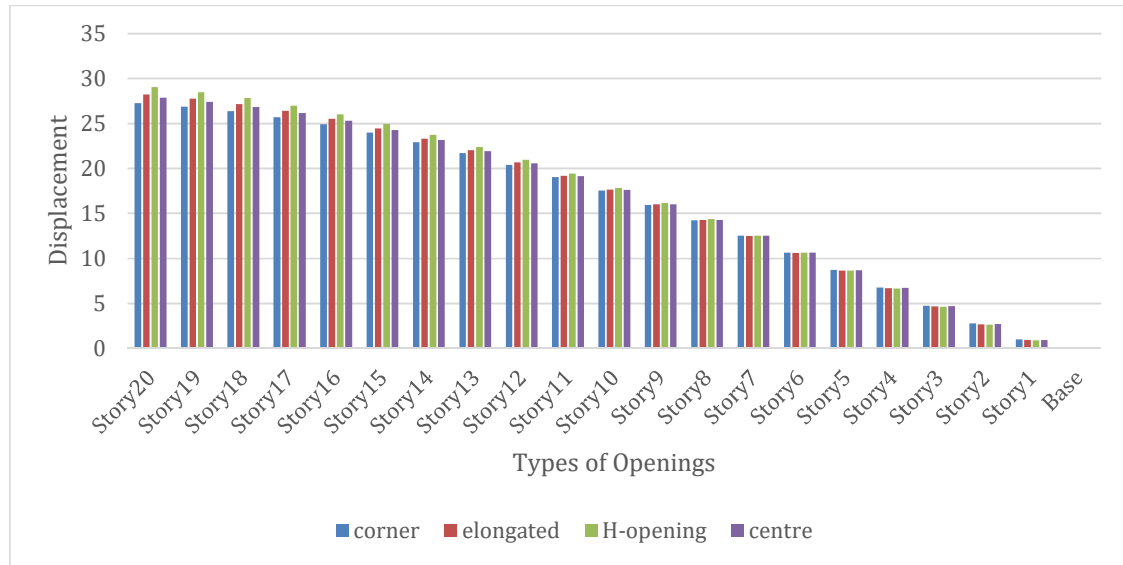


Figure No: 1 Maximum story Displacement in X-Direction

Story	Corner	Elongated	H-opening	Centre
Story20	27.267	28.234	29.035	27.852
Story19	26.895	27.763	28.492	27.425
Story18	26.385	27.156	27.819	26.862
Story17	25.725	26.401	26.998	26.148
Story16	24.918	25.502	26.035	25.289
Story15	23.975	24.47	24.94	24.295
Story14	22.905	23.316	23.725	23.175
Story13	21.717	22.049	22.399	21.941
Story12	20.42	20.679	20.973	20.6
Story11	19.022	19.213	19.454	19.16
Story10	17.526	17.657	17.848	17.626
Story9	15.938	16.015	16.159	16.003
Story8	14.262	14.291	14.391	14.295
Story7	12.502	12.49	12.549	12.505
Story6	10.663	10.616	10.639	10.641
Story5	8.752	8.676	8.669	8.707
Story4	6.781	6.685	6.654	6.718
Story3	4.773	4.667	4.621	4.699
Story2	2.788	2.689	2.643	2.714
Story1	1.027	0.937	0.911	0.948
Base	0	0	0	0

Table No: 1 Maximum story Displacement in X-Direction

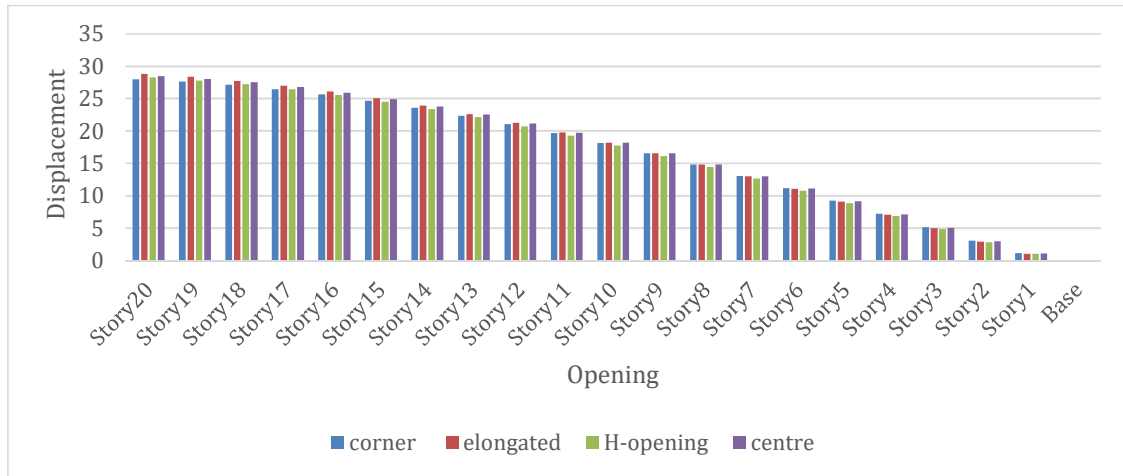


Figure No: 2 Maximum story Displacement in Y-Direction

Story	Corner	Elongated	H-opening	Centre
Story20	27.988	28.826	28.291	28.483
Story19	27.626	28.37	27.822	28.068
Story18	27.117	27.767	27.216	27.507
Story17	26.451	27.011	26.459	26.79
Story16	25.634	26.107	25.559	25.923
Story15	24.678	25.068	24.528	24.919
Story14	23.593	23.905	23.376	23.788
Story13	22.388	22.628	22.114	22.541
Story12	21.073	21.247	20.751	21.186
Story11	19.655	19.768	19.294	19.731
Story10	18.138	18.198	17.749	18.181
Story9	16.527	16.541	16.12	16.54
Story8	14.825	14.799	14.411	14.812
Story7	13.035	12.976	12.626	12.999
Story6	11.163	11.076	10.768	11.107
Story5	9.214	9.106	8.845	9.141
Story4	7.196	7.075	6.865	7.112
Story3	5.129	5.004	4.85	5.038
Story2	3.059	2.944	2.849	2.971
Story1	1.163	1.064	1.026	1.076
Base	0	0	0	0

Table No: 2 Maximum story Displacement in Y-Direction

The maximum displacement occurred at the roof level and gradually decreased towards the base, consistent with cantilever behaviour. The inter-storey displacement was within the IS 1893 limit of $H/250$. Among the configurations, corner openings exhibited the maximum displacement (100%), followed by elongated (96%), H-shaped (93%), and centre openings (91%). Thus, centre openings proved most effective in reducing displacement.

4.2 Storey Drift

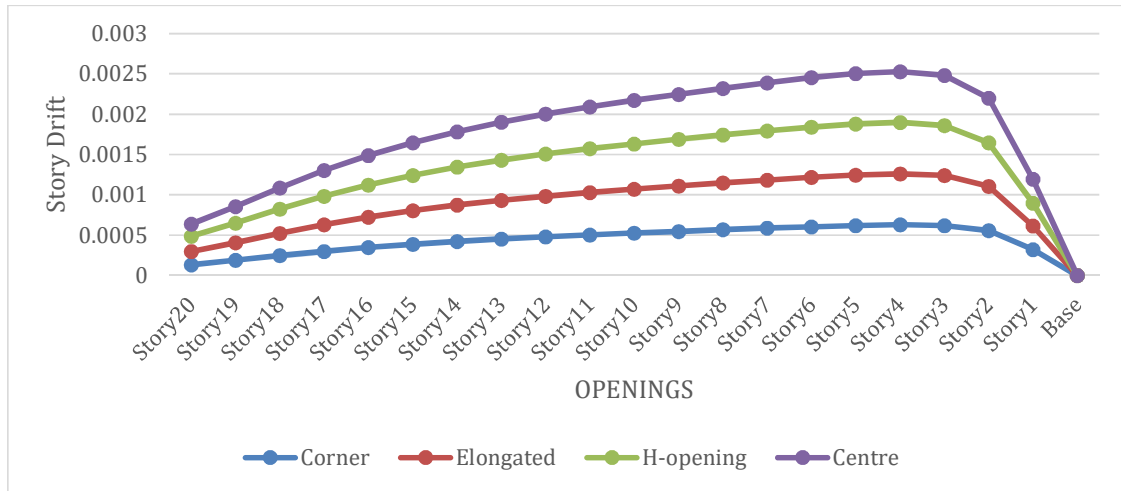


Figure No: 3 Maximum story Drift X-Direction

Story	Corner	Elongated	H-opening	Centre
Story20	0.000133	0.000165	0.000188	0.000151
Story19	0.000189	0.000219	0.000241	0.000206
Story18	0.000247	0.000277	0.0003	0.000264
Story17	0.0003	0.000331	0.000353	0.000318
Story16	0.000347	0.000377	0.000399	0.000365
Story15	0.000388	0.000417	0.000438	0.000405
Story14	0.000423	0.00045	0.000472	0.000439
Story13	0.000454	0.000479	0.000499	0.000469
Story12	0.00048	0.000504	0.000523	0.000495
Story11	0.000504	0.000526	0.000543	0.000518
Story10	0.000526	0.000545	0.000562	0.000539
Story9	0.000547	0.000564	0.000579	0.000558
Story8	0.000567	0.000582	0.000595	0.000577
Story7	0.000587	0.000598	0.00061	0.000595
Story6	0.000604	0.000614	0.000624	0.000612
Story5	0.00062	0.000626	0.000634	0.000625
Story4	0.000629	0.000632	0.000637	0.000632
Story3	0.000621	0.000619	0.000619	0.000621
Story2	0.000558	0.000548	0.000542	0.000552
Story1	0.000321	0.000293	0.000285	0.000296
Base	0	0	0	0

Table No: 3 Maximum story Drift X-Direction

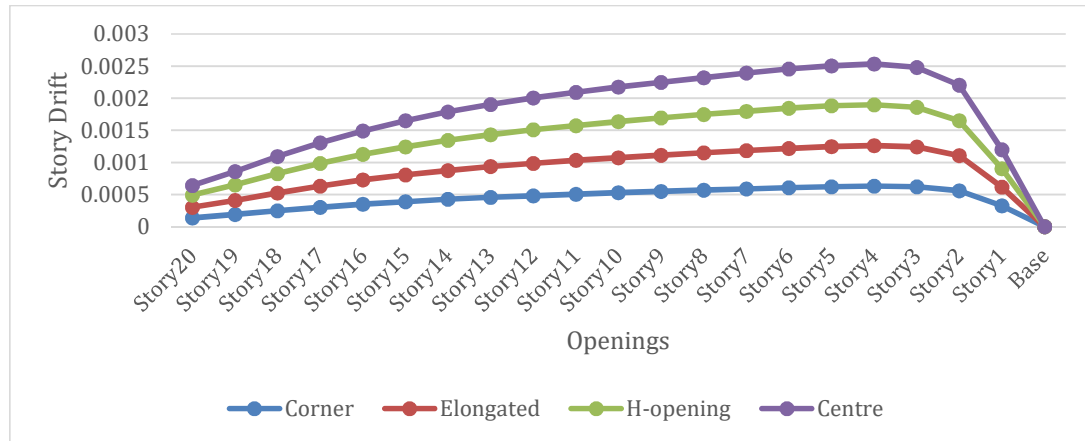


Figure: 4 Maximum story Drift Y-Direction

Story	Corner	Elongated	H-opening	Centre
Story20	0.00013	0.00016	0.000163	0.000147
Story19	0.000191	0.00022	0.000219	0.000207
Story18	0.000252	0.000281	0.000278	0.000269
Story17	0.000308	0.000337	0.000332	0.000325
Story16	0.000356	0.000384	0.000378	0.000373
Story15	0.000398	0.000425	0.000417	0.000414
Story14	0.000433	0.000459	0.000451	0.000449
Story13	0.000464	0.000488	0.000479	0.000479
Story12	0.000491	0.000513	0.000503	0.000504
Story11	0.000515	0.000534	0.000524	0.000527
Story10	0.000537	0.000554	0.000543	0.000548
Story9	0.000558	0.000573	0.000561	0.000568
Story8	0.000579	0.000591	0.000578	0.000587
Story7	0.000599	0.000608	0.000594	0.000605
Story6	0.000618	0.000624	0.000609	0.000623
Story5	0.000635	0.000639	0.000623	0.000639
Story4	0.000648	0.000649	0.000631	0.00065
Story3	0.000648	0.000644	0.000626	0.000646
Story2	0.0006	0.000588	0.000571	0.000592
Story1	0.000363	0.000332	0.000321	0.000336
Base	0	0	0	0

Table No: 4 Maximum story Drift Y-Direction

The inter-storey drift peaked around the mid-height of the structure and reduced at the top. All values were within the IS 1893 permissible drift limit (0.004h per storey). Centre openings recorded the maximum drift (100%), while corner openings showed minimum drift (28%). Elongated and H-shaped openings recorded intermediate drift values of 62% and 88% respectively.

4.3 Base Shear

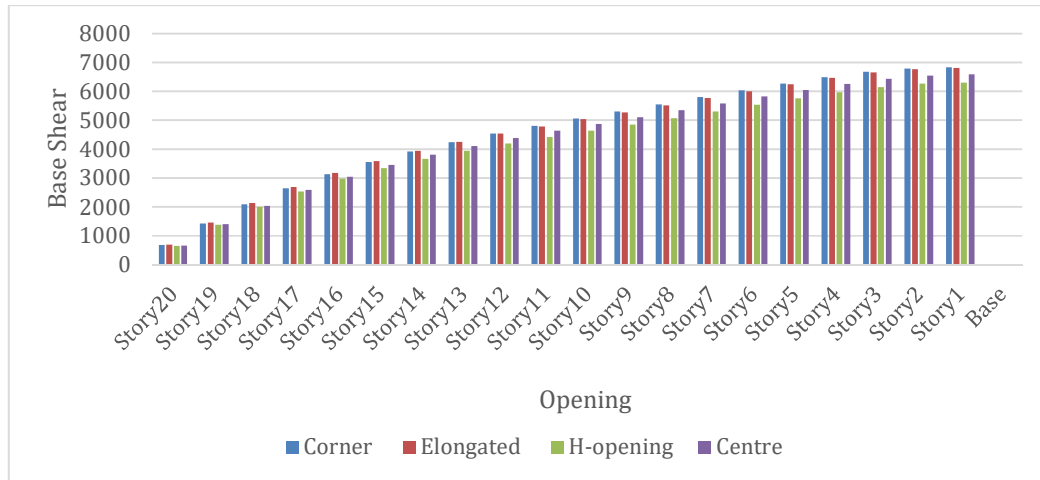


Figure: 5 Maximum Base Shear X-Direction

Story	Corner	Elongated	H-opening	Centre
Story20	686.0733	701.6962	658.7657	672.2781
Story19	1430.551	1463.171	1376.701	1401.096
Story18	2089.268	2131.088	2001.722	2042.543
Story17	2655.419	2699.45	2529.088	2590.534
Story16	3139.195	3179.733	2970.6	3055.719
Story15	3557.869	3590.608	3344.777	3455.641
Story14	3925.493	3947.335	3666.763	3804.562
Story13	4250.318	4259.267	3946.044	4111.045
Story12	4539.572	4534.954	4191.448	4382.797
Story11	4804.095	4786.875	4415.668	4631.219
Story10	5056.831	5029.548	4633.264	4869.696
Story9	5306.9	5273.039	4854.23	5107.531
Story8	5556.199	5519.386	5080.519	5346.588
Story7	5802.14	5765.666	5309.145	5584.172
Story6	6042.316	6008.977	5537.05	5817.719
Story5	6274.278	6246.062	5760.69	6044.434
Story4	6489.633	6467.074	5969.988	6255.337
Story3	6669.511	6651.221	6144.38	6431.002
Story2	6789.486	6772.654	6258.906	6546.989
Story1	6836.203	6818.414	6301.661	6590.831
Base	0	0	0	0

Table No: 5 Maximum Base Shear X-Direction

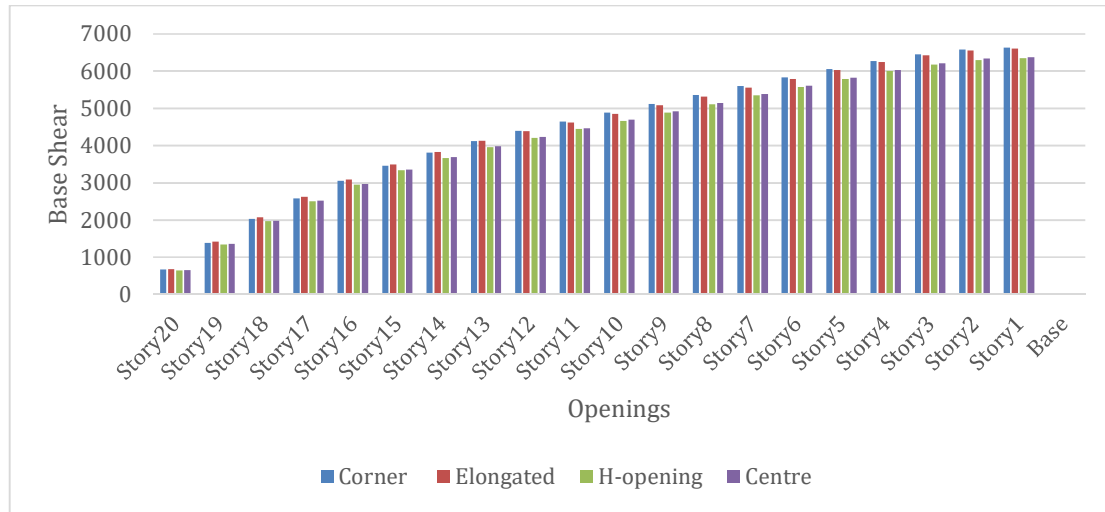


Figure: 6 Maximum Base Shear Y-Direction

Story	Corner	Elongated	H-opening	Centre
Story20	665.732	679.622	642.2876	651.2501
Story19	1391.379	1420.803	1351.046	1360.603
Story18	2034.179	2071.96	1974.597	1985.759
Story17	2585.617	2625.192	2505.62	2518.87
Story16	3054.705	3090.633	2953.68	2969.358
Story15	3458.277	3486.411	3335.817	3354.277
Story14	3810.606	3827.949	3666.545	3688.074
Story13	4120.337	4124.953	3955.026	3979.675
Story12	4394.859	4386.064	4209.402	4236.91
Story11	4645.009	4623.68	4441.271	4471.143
Story10	4883.93	4852.483	4664.288	4695.938
Story9	5121.3	5083.116	4888.302	4921.157
Story8	5359.651	5318.3	5115.761	5149.302
Story7	5596.747	5555.498	5344.199	5378.035
Story6	5830.271	5791.924	5570.886	5604.885
Story5	6057.987	6024.577	5792.883	5827.284
Story4	6272.028	6244.192	6001.453	6036.786
Story3	6453.88	6430.342	6177.546	6214.306
Story2	6578.217	6556.17	6296.215	6334.458
Story1	6628.565	6605.439	6342.565	6381.662
Base	0	0	0	0

Table No: 6 Maximum Base Shear Y-Direction

Base shear increased from top to bottom in all models, reaching maximum values at the foundation. Corner openings attracted the highest base shear (100%), while centre openings attracted the lowest (95%). Elongated and H-shaped openings were close to the corner case, with values of 98% and 97% respectively.

Parameter	Corner Opening	Elongated Opening	H-Opening	Centre Opening
Maximum Storey Displacement (Corner=100%)	100%	96%	93%	91%
Maximum Storey Drift (Centre=100%)	28%	62%	88%	100%
Base Shear (Corner=100%)	100%	98%	97%	95%

Table No: 7 Percentage Comparison of Opening Types Based on Seismic Response

	1st (Best)	2nd	3rd / 4th
Parameter	Centre	H-Opening	Elongated / Corner
	Corner	Elongated	H-Opening / Centre
	Centre	H-Opening	Elongated / Corner

Table No:8 Performance Ranking by Parameter (Best → Worst)

5. Conclusions

This study demonstrates that diaphragm discontinuities strongly influence the seismic behaviour of multi-storey buildings. All configurations remained within IS 1893 drift limits, ensuring structural safety. The analysis shows that corner openings enhance stiffness but attract higher seismic forces, while centre openings reduce base shear but lead to higher drift, creating potential serviceability concerns. Elongated and H-shaped openings offer the most balanced performance, making them preferable for practical applications.

From a management perspective, these findings provide actionable insights for engineers, project managers, and policymakers. Corner openings may be selected where stiffness and strength are priorities, but their higher seismic demand must be considered in foundation design and cost planning. Centre openings may reduce initial costs but require careful drift control to maintain serviceability. Elongated and H-shaped openings represent optimal compromises, improving seismic resilience without significantly increasing material demand.

By linking seismic engineering performance with risk management and construction technology strategies, this research supports informed decision-making in high-rise construction projects, ensuring safer, more economical, and technologically sustainable buildings.

6. References

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