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Performance Based Seismic Analysis on Building with Podium Structure by Considering LSA and tha Methods

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ABSTRACT: Podium-supported high-rise buildings have become increasingly common in urban areas as they allow efficient land utilization while separating commercial and residential functions; however, the introduction of a podium creates irregularities in stiffness and mass distribution that significantly influence seismic behaviour. This study presents a performance-based seismic evaluation of a reinforced concrete (RC) structure consisting of two basement levels, a ground floor, and twenty-three storeys above a podium, modelled and analysed using ETABS software through both Linear Static Analysis and Time History Analysis methods. To assess structural response under varied seismic conditions, ground motion records from the Bhuj, El-Centro, and Nepal earthquakes are applied, representing different characteristics of seismic excitation. The results indicate that Time History Analysis provides a more realistic and accurate representation of the building's dynamic response, particularly in structures exhibiting stiffness and geometric irregularities, whereas Linear Static Analysis tends to produce higher estimates of maximum storey displacement and drift, highlighting its limitations in capturing complex structural behaviour under dynamic loading. Overall, the study emphasizes the importance of adopting dynamic analysis techniques for a more reliable assessment of seismic performance in podium-type high-rise structures.

Keywords: Podium structure, Linear static analysis, Time history analysis.

I. INTRODUCTION

Rapid urban growth and the scarcity of available land in metropolitan areas, particularly in India, have led to a shift from horizontal expansion to vertical development. As a result, high-rise buildings have become a practical solution for efficient land utilization. However, designing tall structures is considerably more challenging than designing low- or mid-rise buildings, as it requires sophisticated analysis and advanced engineering approaches.

To meet increasing space demands and adhere to urban planning requirements—especially for parking—podium structures are widely adopted. A podium serves as the base of a high-rise building and is typically used for purposes such as parking, commercial spaces, or retail facilities. It may be constructed either partially or fully below ground level. Structurally, podiums are important because they contribute significantly to resisting lateral loads and are an integral part of mixed-use developments.

As per Development Control and Promotion Regulations (DCPR) 2034, podium levels with ramps are allowed, provided the height of each level does not exceed 3.2 meters above ground level. Despite their advantages, the inclusion of podiums and basements introduces certain complexities, particularly in terms of soil-structure interaction. One key aspect is the "backstay effect," where underground structural components enhance resistance to lateral forces. This alters the conventional cantilever behavior of buildings, as the ground floor slab and retaining walls actively participate in load resistance.

In podium-type structures, this effect is more pronounced due to the increased stiffness and dimensions of the podium, influencing the overall distribution of lateral forces. Additionally, the presence of multiple basement levels intensifies these interactions, with the transfer of forces largely dependent on the relative stiffness and configuration of shear walls, frames, and diaphragms.

II. METHODOLOGY

The methodology adopted in this study involves the seismic evaluation of a podium-supported high-rise reinforced concrete structure using both linear and nonlinear analytical approaches. The overall procedure includes structural modelling, load definition, application of analysis methods,

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and comparison of results to understand the seismic behaviour of the system.

2.1 Structural Modelling

A three-dimensional model of the building was developed using ETABS software. The structure consists of two basement levels, a ground floor, and twenty-three upper storeys, forming a total of 26 levels. A suitable grid layout and storey data were defined to represent the geometry accurately. Typical floors were assigned a height of 3.0 m, while the podium levels were modelled with a combined height of 9.0 m, resulting in an overall building height of 78 m.

Material properties were specified as M30 grade concrete and Fe415 grade steel. Structural elements such as beams, columns, slabs, and shear walls were assigned appropriate section properties. Slabs were modelled as shell elements, while shear walls were represented using shell or membrane elements. To reflect the increased stiffness and load demand in the podium region, comparatively larger sections were used for columns and walls in these levels. The base of the structure was assumed to be fixed, and a raft foundation system was considered.

2.2 Load Definition and Assignment

All loads acting on the structure were defined in accordance with relevant Indian Standard codes. Dead loads were automatically generated by the software, with additional superimposed dead loads such as floor finishes (1.0–1.5 kN/m²) included manually. Live loads were taken as 3.0 kN/m² for residential floors and 5.0 kN/m² for podium and basement levels.

Seismic loading parameters were defined as per IS 1893 (Part 1):2016, considering seismic Zone III, medium soil conditions (Type II), an importance factor of 1.2, and a response reduction factor of 3.0 corresponding to an Ordinary Moment Resisting Frame (OMRF). The fundamental time period of the structure was determined automatically. Load combinations were generated based on codal provisions, incorporating dead, live, and seismic loads in both principal directions.

2.3 Linear Static Analysis

The equivalent static method was used to evaluate the seismic response under simplified assumptions. The design base shear was calculated as per code provisions and distributed along the building height. Key response parameters such as storey displacement, inter-storey drift, and storey shear were obtained. These values were compared with permissible limits specified in the code, including the maximum allowable drift criterion, to assess structural performance.

2.4 Time History Analysis

To capture the actual dynamic behaviour of the structure, nonlinear time history analysis was performed using recorded earthquake data. Ground motion records from the Bhuj (2001), El Centro (1940), and Nepal (2015) earthquakes were selected to represent different seismic characteristics. These records were processed and scaled to match the design peak ground acceleration as per IS 1893.

The acceleration-time histories were applied at the base of the structure in both orthogonal directions. Each record was defined as an independent load case, and a damping ratio of 5% was considered for the reinforced concrete system. The analysis generated time-dependent responses such as displacement, drift, and storey shear, providing a detailed understanding of the building’s dynamic performance.

2.5 Result Comparison

The results obtained from both analysis methods were extracted and compared using graphical and tabular representations. Parameters such as maximum storey displacement, inter-storey drift, and shear distribution along the height were evaluated. Special attention was given to the behaviour of the podium levels, particularly in terms of stiffness variation and load transfer mechanisms. This comparison enabled the assessment of the effectiveness and limitations of each analysis method in predicting seismic response.

III. MODELING AND ANALYSIS

This study focuses on the performance-based seismic assessment of a reinforced concrete high-rise structure comprising two basement levels, a ground floor, and twenty-three upper storeys (2B+G+23). The building is assumed to be located in Pune, which is categorized under Seismic Zone III according to Indian seismic zoning provisions. The structural model is developed and analysed using ETABS software, employing both linear static analysis and nonlinear time history analysis techniques. The main aim of the study is to examine the seismic response of the building by subjecting it to ground motion records from significant past earthquakes.

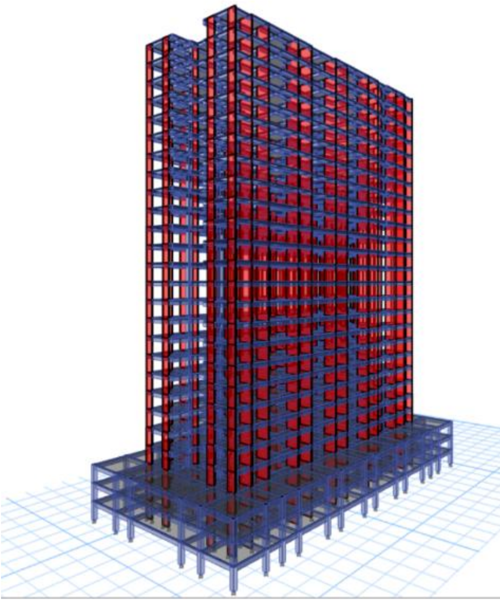

Figure 1: 3D view of building.

The tower portion of the structure measures 52.16 m × 21.05 m, while the podium extends to plan dimensions of 64.16 m × 32.85 m. The building height is based on a typical storey height of 3.0 m, with the podium contributing a combined height of 9.0 m. The structural system is composed of reinforced concrete elements, with M30 grade concrete adopted for slabs, beams, columns, and core walls, and Fe 415 grade steel used for reinforcement. Shear walls are provided at the corners and around the central core to enhance the structure's resistance to lateral forces.

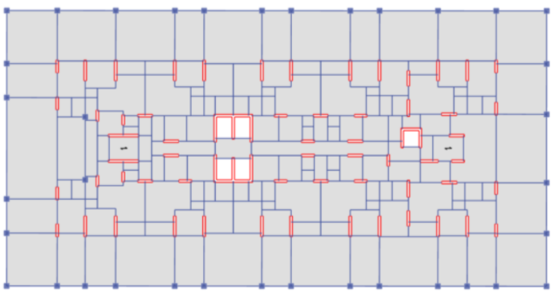

Figure 2: Plan of building with podium-building tower at basement level.

To evaluate the seismic behaviour of the structure, four analytical models were developed in ETABS. Three models were based on time history analysis using actual earthquake ground motion records: Model M1 representing the Bhuj earthquake (2001), Model M2 based on the El-Centro earthquake (1940), and Model M3 corresponding to the Nepal earthquake (2015). An additional model, M4, was created using the equivalent linear static approach to enable comparison with dynamic analysis results. These models were used to study the influence of different seismic inputs on the structural response.

The structure was subjected to standard gravity loads, including self-weight (automatically computed from material properties), a live load of 3.0 kN/m², a floor finish load of 1.5 kN/m², and a wall load of 10 kN/m². Seismic loads were defined in accordance with IS 1893 provisions. For the Pune region, the parameters considered included the appropriate seismic zone classification, a response reduction factor of 3.0 for an ordinary moment-resisting frame (OMRF), medium soil conditions (Type II), and an importance factor of 1.2. These parameters were used to define seismic load cases and to carry out both linear static and time history analyses.

IV. RESULTS AND DISCUSSION

Following results of maximum story drift are obtained after linear static analysis and time history analysis considering Bhuj, El-Centro and Nepal earthquake data.

Table 1: Comparison of Maximum Story Drift for All Models for THA-X Case

Story	Elevation (m)	Max. story drift (mm)			
		Bhuj	El-Centro	Nepal	Linear static
Story 23	78	0.353	0.001	0.129	1.27
Story 22	75	0.385	0.001	0.141	1.379
Story 21	72	0.408	0.001	0.153	1.503
Story 20	69	0.414	0.001	0.167	1.647
Story 19	66	0.402	0.001	0.182	1.796
Story 18	63	0.37	0.002	0.198	1.945
Story 17	60	0.354	0.002	0.213	2.089
Story 16	57	0.374	0.002	0.228	2.225
Story 15	54	0.379	0.002	0.242	2.35
Story 14	51	0.367	0.002	0.255	2.462
Story 13	48	0.337	0.002	0.266	2.559
Story 12	45	0.291	0.002	0.276	2.641
Story 11	42	0.259	0.002	0.283	2.707
Story 10	39	0.242	0.002	0.288	2.754
Story 9	36	0.214	0.002	0.29	2.783

Story 8	33	0.217	0.002	0.288	2.791
Story 7	30	0.266	0.002	0.283	2.777
Story 6	27	0.298	0.002	0.274	2.736
Story 5	24	0.311	0.002	0.261	2.665
Story 4	21	0.305	0.002	0.245	2.558
Story 3	18	0.319	0.002	0.226	2.408
Story 2	15	0.354	0.002	0.203	2.228
Story 1	12	0.347	0.002	0.169	1.946
GF	9	0.294	0.001	0.121	1.478
B1	6	0.251	0.001	0.088	1.076
B2	3	0.133	0.0004276	0.041	0.516

Maximum story drift as per IS 1893(Part 1):2016, clause 7.11.1
Allowable drift = 0.004 x Story hight = 0.004 x 3000 = 12 mm

Story Forces

M1. 2B+G+23 considering Bhuj earthquake

Following table shows maximum story forces for tower considering Bhuj Earthquake for nonlinear time history analysis at the bottom of the storey.

Table 2 : Story Forces in Model 1 considering Bhuj Earthquake

Story	For Storey Force In X-Direction For THA-X Case (kN)	For Storey Force In Y-Direction For THA-Y Case(kN)
Story23	0.3963	0.3998
Story22	0.8948	0.9045
Story21	1.43	1.4455
Story20	2.0007	2.0204
Story19	2.5988	2.6203
Story18	3.2102	3.231
Story17	3.8176	3.8349
Story16	4.4036	4.4151
Story15	4.9544	4.9583
Story14	5.4626	5.4586
Story13	5.9295	5.9185
Story12	6.3652	6.35
Story11	6.7873	6.7716
Story10	7.2177	7.206
Story9	7.6785	7.6749
Story8	8.1871	8.1946
Story7	8.7524	8.7713
Story6	9.371	9.3989
Story5	10.0265	10.0575
Story4	10.6902	10.7155
Story3	11.3241	11.333
Story2	11.9195	11.9025
Story1	12.4484	12.4006
GF	13.1674	13.037
B1	13.6168	13.4076
B2	13.7895	13.5308

Observation: Maximum story force occurs at the base of the structure in X-direction it is observed as 13.78 kN and in Y-direction it is observed 13.53 kN. Forces are observed in decreasing order from bottom towards the top story.

M2. 2B+G+23 considering El-Centro Earthquake

Following table shows story forces for tower considering El-Centro Earthquake for nonlinear time history analysis at the bottom of the storey.

Table 3: Story Forces in Model 2 considering El-Centro Earthquake

Story	For Storey Force In X-Direction For THA-X Case (kN)	For Storey Force In Y-Direction For THA-Y Case (kN)
Story23	7.2278	7.8721
Story22	15.0295	16.2438
Story21	22.0148	23.6481
Story20	28.1127	30.0312
Story19	33.2944	35.3801
Story18	37.5775	39.7324
Story17	41.0238	43.1732
Story16	43.731	45.8248
Story15	49.0758	50.7757
Story14	55.0231	56.6198
Story13	60.2946	61.7335
Story12	64.7455	65.9868
Story11	68.3029	69.3253
Story10	70.9681	71.7704
Story9	75.9575	77.7013
Story8	81.6668	83.319
Story7	86.7893	88.2966

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Story6	91.1543	92.4784
Story5	94.6583	95.7821
Story4	98.846	101.5915
Story3	105.0561	107.6854
Story2	110.8924	113.2726
Story1	115.9257	117.9173
GF	122.6136	123.8319
B1	126.7833	127.2699
B2	128.3836	128.411

Observation: Maximum story force occurs at the base of the structure in X-direction it is observed as 128.38 kN and in Y-direction it is observed 128.41 kN. Forces are observed in decreasing order from bottom towards the top story.

M3. 2B+G+23 considering Nepal Earthquake

Following table shows story forces for tower considering Nepal Earthquake for nonlinear time history analysis at the bottom of the storey.

Table 4: Story Forces in Model 3 considering Nepal Earthquake

Story	For Storey Force In X-Direction For THA-X Case (kN)	For Storey Force In Y-Direction For THA-Y Case (kN)
Story23	0.7445	0.7351
Story22	1.6888	1.6748
Story21	2.7115	2.6937
Story20	3.8104	3.787
Story19	4.9694	4.9376
Story18	6.1607	6.117
Story17	7.3498	7.2902
Story16	8.5015	8.4228
Story15	9.5879	9.4884
Story14	10.5942	10.4744
Story13	11.5225	11.3861
Story12	12.393	12.2462
Story11	13.2403	13.0921
Story10	14.108	13.9684
Story9	15.04	14.9179
Story8	16.0707	15.9724
Story7	17.2171	17.1439
Story6	18.4718	18.4187
Story5	19.801	19.7563
Story4	21.1463	21.092
Story3	22.4308	22.3449
Story2	23.6366	23.4935
Story1	24.6757	24.4481
GF	26.0556	25.6637
B1	26.9157	26.3703
B2	27.2457	26.6049

Observation: Maximum story force occurs at the base of the structure in X-direction it is observed as 27.24 kN and in Y-direction it is observed 26.60 kN. Forces are observed in decreasing order from bottom towards the top story.

M4. 2B+G+23 considering Linear Static Analysis

Following table shows story forces for tower considering linear static analysis for linear static analysis at the bottom of the storey.

Table 5: Story Forces in Model 4 considering Linear Static Analysis

Story	For Storey Force In X-Direction For THA-X Case (kN)	For Storey Force In Y-Direction For THA-Y Case (kN)
Story23	-1082.14	-997.284
Story22	-2259.57	-2082.39
Story21	-3344.69	-3082.43
Story20	-4341.27	-4000.87
Story19	-5253.07	-4841.17
Story18	-6083.87	-5606.83
Story17	-6837.42	-6301.3
Story16	-7517.51	-6928.06
Story15	-8127.89	-7490.58
Story14	-8672.34	-7992.33
Story13	-9154.61	-8436.79
Story12	-9578.49	-8827.43
Story11	-9947.73	-9167.72
Story10	-10266.1	-9461.13
Story9	-10537.4	-9711.14
Story8	-10765.3	-9921.22
Story7	-10953.7	-10094.8
Story6	-11106.3	-10235.5
Story5	-11226.9	-10346.6
Story4	-11319.2	-10431.7
Story3	-11387	-10494.2
Story2	-11436.9	-10540.1
Story1	-11470.5	-10571.1
GF	-11505.2	-10603.1
B1	-11521.1	-10617.7
B2	-11525	-10621.4

Observation: Maximum story force occurs at the base of the structure in X-direction it is observed as -11525 kN and in Y-direction it is observed -10621.4 kN. Forces are observed in decreasing order from bottom towards the top story.

V. CONCLUSION

Conclusion Using ETABS 2022 software, the current study examines the effects of seismic performance of tower with podium structure by linear static analysis and non-linear analysis. The key conclusions from the current study are

- The seismic behaviour of the podium-supported high-rise structure was evaluated using ETABS 2022 through both linear static and nonlinear time history analysis methods.
- The linear static approach resulted in comparatively higher values of maximum storey displacement and inter-storey drift than those obtained from time history analysis using Bhuj, El-Centro, and Nepal earthquake records.
- The calculated storey drift values were within permissible code limits, remaining below 1%, which indicates that the structure meets the Immediate Occupancy (IO) performance level with only minor damage and is safe for use after seismic events.
- Storey forces predicted by the linear static method were lower than those obtained from time history analysis, highlighting differences in force estimation between the two approaches.
- In the linear static method, seismic effects are represented as equivalent lateral loads, whereas time history analysis considers actual ground motion and structural response over time.
- Damping in linear static analysis is incorporated using simplified code-based assumptions, while time history analysis applies more realistic approaches such as Rayleigh or modal damping.
- The linear static method assumes a uniform distribution of mass and stiffness, whereas time history analysis captures multi-modal behaviour, torsional effects, and structural irregularities with greater accuracy.
- Overall, dynamic analysis methods provide a more reliable and realistic evaluation of seismic performance, particularly for complex systems such as podium-type high-rise buildings.

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