To Research for The Effect of Pedestal Structure Modification in High-Rise Buildings

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Abstract - The growing population and limited land in urban areas are driving up demand for towering buildings on a daily basis. India and other emerging countries are seeing an increase in the use of tall buildings. Land becomes unavailable for further expansion in any city, particularly in major cities, beyond a certain point of horizontal development. Consequently, multi-story skyscrapers gained popularity as a means of optimising land use. The design principles used for low- and medium-rise structures are not applicable to high-rise skyscrapers. Tall structures demand the most advanced design techniques since they are intricate engineering tasks. Architects and engineers proposed/put forward the new idea of Podium sort constructions in order to meet the demands of both the growing population and the present bye-laws requiring a minimum parking space for such types of buildings. These days, tower-podium style structures are quite common since they provide for the best possible use of available space on the property and the financial leverage to meet the need for more commercial space. A portion of a structure known as a podium has lateral load resistance greater than that of a tower.

Key Word: *Backstay, Diaphragm, ETABS, Podium Height, lateral forces.*

I. INTRODUCTION

Rapid urbanization and population growth have led to an increasing demand for high-rise buildings in metropolitan and developing cities. Due to limited land availability and rising land costs, vertical construction has become a practical solution for accommodating residential, commercial, and mixed-use developments. Modern high-rise buildings frequently incorporate podium or pedestal structures at their lower levels to provide facilities such as parking areas, shopping complexes, recreational spaces, offices, and other amenities. These podium structures not only enhance the functional utility of the building but also influence its overall structural behavior.

A tower-podium system generally consists of a relatively slender tower supported on a wider and stiffer pedestal structure. The difference in geometry, stiffness, and mass distribution between the tower and podium creates structural discontinuities that can significantly affect the building's response during seismic events. During an earthquake, the interaction between the tower and the pedestal influences the distribution of lateral forces, displacement patterns, storey drift, and dynamic characteristics of the structure.

One of the major challenges associated with tower-podium structures is the variation in stiffness between the tower and the pedestal levels. This abrupt change in stiffness may lead to irregular structural behavior and concentration of seismic forces at specific levels. Consequently, understanding the effect of pedestal modifications on the seismic performance of high-rise buildings is essential for ensuring structural safety and serviceability.

In addition to pedestal height, diaphragm behavior also plays a vital role in the seismic response of a building. Floor diaphragms act as horizontal load-transferring elements that distribute earthquake-induced forces to vertical structural members such as columns, shear walls, and cores. Depending on the modeling assumptions, diaphragms may be considered rigid or semi-rigid. Rigid diaphragms provide greater in-plane stiffness and more uniform force distribution, whereas semi-rigid diaphragms allow limited deformation and provide a more realistic representation of slab behavior.

The seismic performance of a tower-podium system is therefore governed by several factors, including pedestal height, diaphragm rigidity, structural stiffness, mass distribution, and load transfer mechanisms. Modifications in these parameters can significantly alter the dynamic characteristics of the building, such as natural time period, displacement, storey drift, and lateral force resistance.

To evaluate these effects, the present study investigates various tower-podium configurations with different pedestal heights and diaphragm conditions using ETABS software. Response Spectrum Analysis is performed in accordance with IS 1893 (Part 1): 2002 to assess the seismic behavior of the structure. The findings of this study provide valuable insights into the influence of pedestal modifications on high-rise buildings and help identify the most efficient configuration for improved seismic performance and structural stability.

II. OBJECTIVES OF THE STUDY

The primary aim of this research is to investigate the effect of pedestal structure modification on the seismic performance of high-rise buildings. The study focuses on understanding how variations in podium height and diaphragm behavior influence the overall structural response under earthquake loading conditions.

The specific objectives of the study are as follows:

1) To Evaluate the Effect of Pedestal Height on Seismic Performance

The first objective is to examine how different pedestal heights affect the seismic behavior of the building. By considering podium structures of varying heights, the study evaluates their influence on structural stiffness, vibration characteristics, displacement, and overall earthquake resistance.

2) To Compare the Behavior of Rigid and Semi-Rigid Diaphragms

Another important objective is to compare the performance of rigid and semi-rigid diaphragm systems. The study investigates how diaphragm flexibility influences load distribution, structural deformation, lateral stiffness, and dynamic response during seismic excitation.

3) To Analyze Important Seismic Response Parameters

The research aims to evaluate and compare key seismic performance indicators for different structural configurations, including:

- Natural Time Period
- Maximum Storey Displacement
- Storey Drift
- Lateral Force Distribution
- Overall Structural Stiffness

These parameters provide a comprehensive understanding of the structural behavior under earthquake loading.

4) To Identify the Most Efficient Pedestal Configuration

The study seeks to determine the optimum tower-podium configuration that offers the best seismic performance. The comparison of different pedestal heights and diaphragm conditions helps identify the structural arrangement that minimizes displacement and drift while maximizing stiffness and lateral load resistance.

5) To Develop Recommendations for High-Rise Building Design

Based on the analytical findings, the study aims to provide practical recommendations for the design of tower-podium structures in seismic regions. These recommendations can assist structural engineers in selecting appropriate podium configurations and diaphragm systems to enhance the safety, stability, and performance of high-rise buildings during earthquakes.

6) To Contribute to Earthquake-Resistant Structural Design

The final objective is to contribute to the existing knowledge on tower-podium interaction and seismic behavior, thereby supporting the development of more efficient and earthquake-resistant high-rise structures in urban environments.

Through these objectives, the study aims to establish a clear understanding of the role of pedestal structures and diaphragm behavior in improving the seismic performance of modern high-rise buildings.

III. METHODOLOGY

The present study was conducted to investigate the effect of pedestal structure modification on the seismic behavior of high-rise buildings. The analysis was carried out using ETABS software, and the seismic performance of different tower-pedestal configurations was evaluated through Response Spectrum Analysis in accordance with IS 1893 (Part 1): 2002.

3.1 Literature Review and Code Study

Initially, an extensive literature review was performed to understand the behavior of tower-podium structures under seismic loading. Previous research studies related to pedestal structures, diaphragm behavior, backstay effects, and high-rise building performance were examined. Relevant provisions from IS 1893 (Part 1): 2002 and IS 16700:2017 were also studied to establish the analysis parameters and design criteria.

3.2 Development of Structural Models

To assess the influence of pedestal height and diaphragm conditions, different structural models were developed. The base model consisted of a 25-storey reinforced concrete tower without a pedestal. Additional models were created by introducing pedestal structures of varying heights (3, 4, and 5 storeys) with both rigid and semi-rigid diaphragm conditions. This enabled a comparative assessment of the structural response due to changes in podium configuration.

3.3 ETABS Modeling

All structural models were developed using ETABS 2016. The building geometry, material properties, member sizes, loading conditions, and support conditions were defined according to the project requirements.

The following modeling parameters were adopted:

- Tower dimensions: 25 m × 25 m
- Pedestal dimensions: 75 m × 75 m
- Concrete grade: M30
- Reinforcement steel grade: Fe500
- Beam size: 300 mm × 550 mm
- Column size: 300 mm × 750 mm
- Shear wall thickness: 200 mm

Dead loads, live loads, floor finish loads, and seismic loads were assigned as per Indian Standard provisions. The diaphragm conditions were assigned separately for each model to study their effect on lateral load resistance.

3.4 Response Spectrum Analysis

Response Spectrum Analysis (RSA) was carried out to determine the dynamic response of the building under earthquake loading. This method considers the contribution of multiple vibration modes and provides a realistic estimate of seismic behavior for high-rise structures.

The seismic parameters used in the analysis were:

- Seismic Zone: III
- Zone Factor (Z): 0.16
- Importance Factor (I): 1.2
- Response Reduction Factor (R): 5
- Soil Condition: Medium Soil

The modal responses obtained from different vibration modes were combined using standard modal combination techniques to evaluate the overall structural response.

3.5 Extraction and Comparison of Results

After completing the analysis, important seismic response parameters were extracted from ETABS for each model. These parameters included:

- Natural Time Period
- Maximum Storey Displacement
- Storey Drift
- Lateral Force Distribution

The results obtained from various models were tabulated and graphically represented. Comparative analysis was performed to identify the effect of pedestal height and diaphragm type on the seismic performance of the structure.

3.6 Conclusions and Design Recommendations

Based on the analytical results, conclusions were drawn regarding the most effective pedestal configuration for improving structural performance during earthquakes. Recommendations were provided concerning optimum pedestal height, diaphragm selection, and overall tower-podium design to enhance stiffness, reduce displacement, and improve seismic stability in high-rise buildings.

This methodology provides a systematic approach for evaluating the seismic behavior of pedestal-modified high-rise buildings and supports the development of safer and more efficient structural designs.

IV. BUILDING CONFIGURATION AND DESIGN PARAMETERS

4.1 Structural Details

The study considers a reinforced concrete (RC) high-rise building consisting of 25 storeys. The structure comprises a central tower supported by a pedestal (podium) structure, which serves as the transfer platform between the tower and the foundation system. The dimensions and material properties were selected based on typical high-rise residential and commercial building practices.

The tower has a plan dimension of **25 m × 25 m**, while the pedestal structure extends to **75 m × 75 m**, creating a significant variation in stiffness and mass distribution between the tower and podium levels. This configuration allows the investigation of the influence of pedestal modifications on the seismic behavior of the structure.

The structural framing system consists of reinforced concrete beams and columns. Beams with dimensions of **300 mm × 550 mm** are provided to ensure adequate flexural and shear capacity under gravity and lateral loading conditions. Columns are designed with dimensions of **300 mm × 750 mm** to provide sufficient axial load-carrying capacity and lateral stiffness.

The building utilizes **M30 grade concrete**, which has a characteristic compressive strength of 30 MPa, ensuring durability and structural strength. Reinforcement is provided using **Fe500 grade steel**, having a yield strength of 500 MPa, which enhances the ductility and load-resisting capacity of the structural members.

To improve resistance against lateral loads and control excessive displacement, **200 mm thick reinforced concrete shear walls** are incorporated into the structural system. The shear walls contribute significantly to the overall stiffness and stability of the building during seismic events.

Structural Parameters Used in the Study

Parameter	Value
Number of Storeys	25
Tower Dimensions	25 m × 25 m
Pedestal Dimensions	75 m × 75 m
Beam Size	300 mm × 550 mm
Column Size	300 mm × 750 mm
Concrete Grade	M30
Reinforcement Grade	Fe500
Shear Wall Thickness	200 mm

4.2 Seismic Parameters

The seismic analysis of the building was carried out in accordance with the provisions of **IS 1893 (Part 1): 2002**, which specifies the criteria for earthquake-resistant design of structures in India. Since the building is assumed to be located in Pune, Maharashtra, the seismic parameters corresponding to **Seismic Zone III** were adopted.

The **Zone Factor (Z)** was taken as **0.16**, representing the expected intensity of seismic shaking in the region. This factor reflects the seismic hazard associated with Zone III areas and is used in the calculation of design seismic forces.

An **Importance Factor (I)** of **1.2** was considered to account for the significance of the structure and the potential consequences of failure during an earthquake. The importance factor increases the design seismic forces to provide an additional margin of safety.

The **Response Reduction Factor (R)** was assumed as **5**, representing a special moment-resisting reinforced concrete frame system with adequate ductile detailing. This factor accounts for the energy dissipation capacity of the structure through inelastic behavior during severe seismic events.

These seismic parameters were incorporated into the Response Spectrum Analysis to evaluate the dynamic behavior of different pedestal configurations and diaphragm conditions.

Seismic Parameters Used in Analysis

Parameter	Value
Seismic Zone	III
Zone Factor (Z)	0.16
Importance Factor (I)	1.2
Response Reduction Factor (R)	5
Analysis Method	Response Spectrum Analysis
Design Code	IS 1893 (Part 1): 2002

The selected seismic parameters provide a realistic representation of earthquake loading conditions and enable a comprehensive evaluation of the seismic performance of the tower-pedestal structural system.

V. MODEL DISCRIPTION

To investigate the influence of pedestal height and diaphragm behavior on the seismic performance of high-rise buildings, seven different structural models were developed and analyzed using ETABS. The models were created by varying the number of pedestal storeys and diaphragm conditions while maintaining the same tower geometry, material properties, and loading conditions. This approach enabled a systematic comparison of the structural response of the building under earthquake loading.

The base model (M1) consisted of a tower structure without any pedestal, serving as a reference model for evaluating the effectiveness of pedestal modifications. Subsequently, podium structures of 3, 4, and 5 storeys were introduced beneath the tower. For each podium height, both rigid and semi-rigid diaphragm conditions were considered to examine their impact on lateral load distribution and overall structural behavior.

The details of the models considered in the study are described below:

Model M1 – Tower without Podium (T)

Model M1 represents the conventional high-rise building without a pedestal structure. The tower extends directly from the foundation level to the top storey. This model serves as the control or reference model against which all other podium configurations are compared. The seismic performance parameters obtained from this model provide a baseline for assessing the effectiveness of pedestal structures in improving building behavior during earthquakes.

Model M2 – Tower + 3-Storey Podium with Rigid Diaphragm (T+3-R)

In this model, a three-storey pedestal structure is provided beneath the tower. The floor slabs are assigned rigid diaphragm behavior, assuming that the slab remains undeformed within its plane and transfers lateral loads uniformly to the vertical structural elements. This model helps evaluate the effect of a relatively low-height podium combined with maximum diaphragm stiffness.

Model M3 – Tower + 3-Storey Podium with Semi-Rigid Diaphragm (T+3-S)

Model M3 has the same structural configuration as Model M2 but incorporates a semi-rigid diaphragm instead of a rigid diaphragm. The semi-rigid diaphragm allows in-plane deformation of the floor slab, resulting in a more realistic representation of load transfer mechanisms. The comparison between M2 and M3 highlights the influence of diaphragm flexibility on seismic response.

Model M4 – Tower + 4-Storey Podium with Rigid Diaphragm (T+4-R)

This model consists of a tower supported on a four-storey pedestal structure with rigid diaphragm action. Increasing the podium height alters the stiffness and mass distribution of the building. The purpose of this model is to assess the effect of increasing podium levels while maintaining rigid floor behavior.

Model M5 – Tower + 4-Storey Podium with Semi-Rigid Diaphragm (T+4-S)

Model M5 is similar to Model M4, except that semi-rigid diaphragm action is assigned to the floor slabs. This model allows evaluation of the combined influence of increased podium height and diaphragm flexibility on the seismic performance of the building.

Model M6 – Tower + 5-Storey Podium with Rigid Diaphragm (T+5-R)

Model M6 incorporates a five-storey pedestal structure beneath the tower with rigid diaphragm behavior. Among all the regular podium configurations considered in the study, this model has the maximum pedestal height. The increased podium height enhances the overall stiffness of the structure and significantly affects the dynamic characteristics such as time period, displacement, and storey drift.

Model M7 – Tower + 5-Storey Podium with Semi-Rigid Diaphragm (T+5-S)

Model M7 has the same geometric configuration as Model M6 but utilizes semi-rigid diaphragm behavior. This model is used to study the influence of diaphragm flexibility in taller pedestal structures and to compare its performance with the rigid diaphragm counterpart. The results from this model help determine whether the increased flexibility of the diaphragm has a significant effect on seismic response.

Comparative Purpose of the Models

The seven models were developed to achieve the following objectives:

- To evaluate the influence of pedestal height on structural stiffness and seismic response.
- To compare the behavior of rigid and semi-rigid diaphragms under earthquake loading.
- To investigate changes in natural time period, displacement, storey drift, and lateral force due to pedestal modifications.
- To identify the most efficient tower-podium configuration for improved seismic performance.
- To establish design recommendations for high-rise buildings incorporating pedestal structures.

The comparative analysis of these models provides valuable insights into the role of podium structures and diaphragm conditions in enhancing the seismic performance and overall stability of high-rise buildings.

V. RESULTS AND DISCUSSION

The seismic performance of the seven structural models was evaluated using Response Spectrum Analysis in ETABS. The effect of varying pedestal heights and diaphragm conditions was studied by comparing important structural response parameters such as natural time period, displacement, storey drift, and lateral force. The results obtained from the analysis are discussed below.

5.1 Time Period

The natural time period is one of the most important dynamic properties of a structure, representing the time required to complete one cycle of free vibration. It is directly related to the stiffness and mass of the building. A lower time period generally indicates a stiffer structure, whereas a higher time period indicates greater flexibility.

The results show that the fundamental time period decreases progressively with the increase in pedestal height. The base model, M1 (Tower without Podium), exhibited the highest fundamental time period of **2.397 seconds**, indicating comparatively lower stiffness. In contrast, Model M6 (Tower + 5-Storey Podium with Rigid Diaphragm) showed the lowest time period of **2.216 seconds**, demonstrating increased structural stiffness due to the presence of a taller podium structure.

The reduction in time period can be attributed to the additional stiffness provided by the pedestal levels, which improve the overall lateral load-resisting capacity of the building. It was observed that the reduction in time period ranged between approximately **10–15%** as the podium height increased from three to five storeys.

Furthermore, models with semi-rigid diaphragms consistently exhibited slightly higher time periods compared to their rigid diaphragm counterparts. This behavior occurs because semi-rigid diaphragms allow in-plane deformation of floor slabs, reducing the overall lateral stiffness of the structure. As a result, buildings with semi-rigid diaphragms tend to behave more flexibly under seismic loading.

The results indicate that increasing podium height significantly improves structural stiffness and reduces the natural vibration period, thereby enhancing seismic performance.

5.2 Displacement

Storey displacement refers to the lateral movement of a building under seismic forces. Excessive displacement may lead to structural damage, serviceability issues, and discomfort for occupants. Therefore, controlling displacement is an important aspect of earthquake-resistant design.

The analysis results show that displacement gradually increases from the base to the top storey in all models, with the maximum displacement occurring at the roof level. The maximum top-storey displacement recorded for Model M1 was **193.416 mm**, while Model M6 exhibited a reduced displacement of **188.102 mm**.

The reduction in displacement demonstrates the positive effect of increasing pedestal height on structural performance. The additional podium levels increase the stiffness of the lower portion of the building, resulting in better resistance against lateral forces. The overall reduction in displacement was observed to be approximately **5–10%** for the models with taller podium structures.

A comparison between rigid and semi-rigid diaphragm models revealed that semi-rigid diaphragms produced slightly higher displacement values. Since semi-rigid diaphragms permit slab deformation, the lateral loads are distributed less efficiently compared to rigid diaphragms. Consequently, the structure experiences slightly larger lateral movements.

The results clearly indicate that podium structures contribute significantly to reducing lateral displacement, thereby improving the serviceability and stability of high-rise buildings subjected to earthquake loading.

5.3 Storey Drift

Storey drift is defined as the relative lateral displacement between two consecutive storeys divided by the storey height. It is one of the most critical parameters in seismic design because excessive drift can cause damage to structural and non-structural components such as partitions, cladding, glazing, and utility systems.

The analysis results indicate that the storey drift values for all models remained within the permissible limits specified by IS 1893. The drift generally increased with height and reached maximum values in the middle to upper storeys before decreasing near the roof level.

Models with rigid diaphragms exhibited lower storey drift values compared to the corresponding semi-rigid diaphragm models. This behavior is primarily due to the greater in-plane stiffness of rigid diaphragms, which allows more efficient distribution of lateral loads among the structural members.

The influence of pedestal height was also significant. As the podium height increased, the overall structural stiffness improved, resulting in reduced drift values. Models M6 and M7, which incorporated five-storey podiums, showed better drift control compared to the three-storey and four-storey podium models.

Although semi-rigid diaphragm models experienced slightly higher drift values, the differences were relatively small and remained within acceptable design limits. These findings confirm that taller podium structures improve the seismic stability of high-rise buildings by limiting inter-storey deformation.

5.4 Lateral Force

Lateral force represents the seismic force acting on each storey level due to earthquake excitation. The magnitude and distribution of lateral forces depend on the mass, stiffness, and dynamic characteristics of the structure.

The analysis revealed that lateral force values increased with the increase in pedestal height. Models incorporating taller podium structures attracted greater seismic forces due to their increased stiffness. Among all the models considered, the **T+5 podium configuration (M6 and M7)** exhibited the highest lateral force resistance.

This increase in lateral force should not be interpreted as a disadvantage. In seismic analysis, a stiffer structure generally attracts higher seismic forces while simultaneously reducing displacement and drift. Therefore, the increase in lateral force indicates improved structural participation in resisting earthquake loads.

A comparison between rigid and semi-rigid diaphragm conditions showed that rigid diaphragm models developed slightly higher lateral forces than semi-rigid diaphragm models. The rigid diaphragm ensures more uniform load transfer to the vertical load-resisting elements, resulting in greater force distribution efficiency. On the other hand, semi-rigid diaphragms allow floor deformation, leading to a marginal reduction in the lateral force transferred to structural members.

Overall, the results demonstrate that increasing podium height enhances the lateral load-resisting capability of the building and improves its seismic performance. The five-storey podium configuration with a rigid diaphragm exhibited the most favorable behavior in terms of stiffness, displacement control, drift reduction, and lateral force resistance.

VII. CONCLUSIONS

The present study was carried out to investigate the effect of pedestal structure modification and diaphragm behavior on the seismic performance of high-rise buildings using Response Spectrum Analysis in ETABS. Seven different structural models with varying pedestal heights and diaphragm conditions were analyzed and compared based on key seismic response parameters such as time period, displacement, storey drift, and lateral force.

Based on the analytical results obtained from the study, the following conclusions can be drawn:

1) Increasing Pedestal Height Enhances Structural Stiffness

The analysis results indicate that increasing the pedestal height significantly improves the overall stiffness of the building. Taller pedestal structures provide additional lateral resistance and strengthen the interaction between the tower and the foundation system. As the podium height increased from three storeys to five storeys, the building became stiffer and exhibited improved seismic performance.

2) The Five-Storey Pedestal Model Exhibited the Best Seismic Performance

Among all the models analyzed, the Tower + 5-Storey Podium configuration demonstrated the most favorable behavior under earthquake loading. This model showed lower time periods, reduced displacements, better drift control, and higher lateral force resistance compared to the other configurations. The results confirm that a taller pedestal structure contributes positively to the seismic stability of high-rise buildings.

3) Natural Time Period Reduced with Increase in Pedestal Height

The fundamental natural time period of the structure decreased by approximately 10–15% as the pedestal height increased. This reduction indicates an increase in structural stiffness and a decrease in flexibility. The lowest time period was observed in the model with a five-storey pedestal and rigid diaphragm, demonstrating its superior resistance to lateral vibrations caused by seismic forces.

4) Storey Displacement Reduced Significantly

The maximum lateral displacement of the building decreased by approximately 5–10% with increasing pedestal height. Reduced displacement indicates improved resistance to earthquake-induced lateral movement and better serviceability performance. The models with taller podium structures effectively controlled the overall sway of the building under seismic loading.

5) Rigid Diaphragms Performed Better than Semi-Rigid Diaphragms

The comparison between diaphragm conditions revealed that rigid diaphragms provide better seismic performance than semi-rigid diaphragms. Rigid diaphragms distribute lateral forces more efficiently among the structural elements, resulting in lower displacement, reduced storey drift, and shorter time periods. Semi-rigid diaphragms, due to their flexibility, exhibited slightly higher deformation and vibration characteristics.

6) One-Sided Pedestal Configurations Increased Structural Flexibility

The analysis of one-sided pedestal configurations showed that structural irregularity negatively affects seismic behavior. These models exhibited higher displacement values and longer natural time periods compared to regular pedestal configurations. The uneven stiffness distribution created by the one-sided pedestal increased the flexibility of the structure and reduced its overall seismic efficiency.

7) Regular Pedestal Configurations Provide Better Lateral Stability

The study demonstrates that regular and symmetrical pedestal arrangements offer superior lateral stability compared to irregular configurations. Uniform distribution of stiffness and mass allows more efficient transfer of seismic forces throughout the structure, resulting in improved structural performance and reduced deformation during earthquakes.

8) Overall Conclusion

The results of this research clearly demonstrate that pedestal structure modification plays a significant role in influencing the seismic behavior of high-rise buildings. Increasing pedestal height improves structural stiffness, reduces displacement and time period, and enhances lateral load resistance. Furthermore, rigid diaphragm systems perform more effectively than semi-rigid diaphragms in controlling seismic response. Based on the findings, a regular five-storey pedestal configuration with a rigid diaphragm can be recommended as the most efficient arrangement among the models considered in this study for achieving improved seismic performance and structural stability in high-rise buildings.

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