

Study of G+20RCC Building in Seismic Zone V Using Soil Structure Interaction

Prof. Vishwajeet Kadlag¹, Nitin Shivaji Najan²

Professor¹, PG Student²

Department of Structural Engineering

DY Patil School of Engineering, Lohegaon, Maharashtra, India

Author's Email Id: nitinnajan7777@gmail.com²

Abstract

This thesis investigates the impact of Soil-Structure Interaction (SSI) on the seismic performance of re-inforced concrete (RCC) building. The study focuses G+20 storey RCC buildings located in Seismic Zone V, modelled using ETABS software. A three-layer soil profile, including soft clay (0–5 m), me-dium-dense sandy silt (5–15 m), and dense sand/gravel (15–30 m), is incorporated to simulate realistic soil behavior. The analysis compares buildings with flexible-base condition, examining base shear, lateral displacements, storey drifts, overturning moments, and performance points.

Results show that considering SSI increases the building's natural period, leading to a reduction in base shear and overturning moments, but causing increased lateral displacements and storey drifts. The study also compares drift values with allowable limits as per IS 1893:2016, confirming that all models comply with seismic deflection requirements but may approach wind deflection limits in flexible-base models.

The findings highlight the importance of considering SSI for a more accurate seismic design, as fixed-base assumptions may lead to unsafe or inefficient designs. This research provides insights into incorpo-rating realistic soil conditions in seismic design, particularly for high-rise buildings in seismic zones.

Keywords: *Soil-Structure Interaction (SSI), ETABS, RCC Buildings, Seismic Zone V, Base Shear, Storey Drift, Performance Point, Seismic Design.*

INTRODUCTION

The safety and stability of high-rise buildings during seismic events are a primary concern in earthquake engineering, particularly in regions classified under high seismic risk zones. Among the various factors influencing the seismic performance of buildings, one of the most crucial is the interaction between the structure and the underlying soil. This interaction, known as Soil-Structure Interaction (SSI), plays a significant role in determining the overall behavior of buildings during earthquakes. In many traditional approaches, the foundation is considered to be rigid, neglecting the dynamic effects that the soil exerts on the building during seismic loading. However, this assumption often leads to inaccurate predictions of structural response and, in certain cases, can compromise safety.

In earthquake-prone regions, particularly those in Seismic Zone V as per Indian seismic classification, this issue becomes even more critical. Seismic Zone V encompasses areas with the highest level of seismic activity, making the need for accurate seismic analysis essential. Seismic Zone V covers several parts of India, including the Himalayan region, where the potential for high-magnitude earthquakes exists. In such areas, buildings are often subjected to severe shaking, which can lead to significant lateral forces and accelerations, potentially causing damage or collapse if not appropriately designed.

Traditional seismic analysis methods, often based on fixed-base models, tend to overlook the role of the soil in the seismic response of buildings. The assumption that the foundation is rigid or non-deformable fails to account for the effects of soil stiffness and damping. The interaction between the structure and the foundation soil can significantly alter the behavior of the structure, influencing parameters such as displacement, drift, base shear, and overturning moments. Therefore, it is essential to incorporate Soil-Structure Interaction (SSI) into seismic analysis for a more realistic and accurate understanding of building performance during seismic events.

PROBLEM STATEMENT

In Seismic Zone V, the occurrence of high-intensity earthquakes poses a significant threat to the safety of buildings and infrastructure. Many structures in these regions are designed without incorporating SSI effects, relying on simplified methods that assume a rigid foundation. These traditional approaches can result in designs that either overestimate the building's ability to resist seismic forces or fail to account for the true effects of soil flexibility, leading to unsafe or inefficient designs. The problem, therefore, lies in the lack of comprehensive understanding and consideration of Soil-Structure Interaction (SSI) in the design of buildings located in high seismic risk zones.

This research seeks to address this gap by performing a detailed study of a G+20 RCC (Reinforced Ce-ment Concrete) building under seismic loading in Seismic Zone V, incorporating Soil-Structure Interac-tion (SSI) into the analysis. The goal is to understand how SSI impacts the seismic response of high-rise buildings and how the results compare to traditional fixed-base assumptions.

Advantages of Considering Soil-Structure Interaction (SSI) in Seismic Analysis

More Accurate Structural Behavior: SSI provides a realistic representation of the building's behavior under seismic loading, improving predictions of displacement, drift, and lateral forces.

- **Improved Displacement and Drift Predictions:** Including SSI results in more accurate storey drift and displacement values, ensuring compliance with seismic deflection limits and identifying potential structural vulnerabilities.
- **Better Base Shear and Overturning Moment Estimates:** SSI reduces base shear and overturning moments, leading to more efficient designs and cost savings in foundation construction.
- **Realistic Seismic Performance:** Incorporating SSI offers a better understanding of the building's performance point, capacity curves, and stability during earthquakes.

- **Optimized Foundation Design:** SSI helps in designing cost-effective and safe foundations by accounting for soil flexibility and damping effects, improving structural resilience.
- **Enhanced Risk Assessment:** By considering SSI, engineers can more accurately assess and mitigate risks, such as excessive displacements or foundation failure.
- **Code Compliance:** SSI-based analysis ensures compliance with seismic codes like IS 1893:2016, reducing the risk of non-compliance and improving safety.
- **Increased Structural Resilience:** SSI contributes to a more resilient structure by accounting for the damping effects of soil, reducing damage during seismic events.
- **Applicable to Other Structures:** The methodology and insights from the study can be applied to other buildings or infrastructure in seismic zones, improving safety and performance.
- **Contribution to Seismic Engineering:** This study provides valuable insights into SSI, contributing to safer, more accurate designs in earthquake-prone areas.

OBJECTIVES OF THE STUDY

The primary objective of this study is to investigate the effects of Soil-Structure Interaction (SSI) on the seismic performance of a G+20 RCC building located in Seismic Zone V. The study aims to:

- Analyze the seismic response of the building with and without considering SSI using nonlinear static pushover analysis.
- Investigate the influence of SSI on key seismic parameters such as base shear, displacement, inter-storey drift, and performance point.
- Compare the seismic performance of the building under fixed-base and flexible-base conditions to assess the impact of SSI on lateral forces, displacement patterns, and building safety.

- Evaluate the compliance of the building's response with seismic design codes such as IS 1893:2016, ensuring it meets safety and performance requirements under earthquake loading.

SCOPE OF THE STUDY

The scope of this study includes the analysis of a G+20 RCC building subjected to seismic forces in Seismic Zone V, with the incorporation of Soil-Structure Interaction (SSI). The study is focused on the following:

- **Soil Profile:** The analysis considers a three-layer soil profile comprising soft clay (0–5 meters), medium-dense silty sand (5–15 meters), and dense sand with gravel (15–30 meters). These soil layers are typical of regions within Seismic Zone V.
- **Building Model:** The building is modelled as a reinforced concrete framed structure, incorporating typical material properties and design parameters in line with current building codes.
- **Seismic Analysis:** Nonlinear static pushover analysis is used to evaluate the building's response under seismic loading. The analysis is performed for both fixed-base and flexible-base conditions to assess the influence of SSI.
- **Performance Evaluation:** The study evaluates key seismic parameters such as base shear, storey displacement, and inter-storey drift. The results are compared to the design criteria outlined in IS 1893:2016 to ensure the building's performance meets the required safety standards.

LITERATURE REVIEW

Bhupendra Sharma, Abhijeet Galatage (2021) examined “Study of Pushover Analysis of RCC Building with Soft Story at Different Elevations”, This research centers on the seismic evaluation of multi-story reinforced concrete (RC) frame buildings through pushover analysis. In this method, the structure is subjected to gradually increasing lateral loads applied in a fixed distribution pattern along the height, continuing until the building reaches predetermined performance objectives or target displacements. The devastating Bhuj earthquake of 2001

highlighted the susceptibility of many RC structures in India, especially high-rise buildings in urban areas like Gujarat. This disaster underscored the urgent need to reassess the seismic resilience of numerous buildings originally designed only for vertical or gravity loads.

Given the repeated damage and collapse of concrete buildings in recent seismic events, evaluating their structural performance under earthquake conditions has become a critical concern. Earthquake-prone countries like India must adopt straightforward and practical methods for assessing building vulnerability to enhance preparedness and safety. In the context of disaster risk reduction and human safety, predicting how buildings will behave during seismic events is of paramount importance.

To ensure compliance with national safety standards, the structural performance of buildings is assessed against the seismic design criteria outlined in IS 1893: 2002. The analysis process employed in this study uses the capacity spectrum method as detailed in ATC-40, and the distribution of lateral forces during pushover analysis follows the guidelines provided in IS 1893 (Part 1): 2002.

This approach is applied to a standard RC moment-resisting frame (MRF) building. By employing this methodology, engineers can obtain a clearer picture of how damage is distributed across the structure and better understand the sequence and nature of its potential failure mechanisms during an earthquake. This information is vital for prioritizing retrofitting and strengthening strategies in existing buildings, ensuring they meet essential seismic performance objectives.

Alesh Matala, Prof. Amey Khedikar (2018) presented “Soil - Structure Interaction of Multistorey R.C.C. Frames” This study focuses on evaluating the behavior of frame buildings, particularly those constructed prior to the implementation of seismic design codes introduced in the 1970s. While previous experimental and analytical research has extensively explored the seismic performance of such buildings and identified their vulnerabilities, most of these analyses have traditionally been conducted under the assumption of a fixed-base condition, thereby neglecting the influence of soil and foundation flexibility.

In this research, the interaction between the superstructure and the substructure—referred to as Soil-Structure Interaction (SSI)—is explored to provide a more realistic representation of a building’s behavior during seismic events. The soil is modeled using simplified assumptions that are sufficient to capture the essential features of the overall system response without introducing unnecessary computational complexity. With advancements in analytical modeling and the development of more accurate hysteresis models in recent years, it has become possible to better simulate structural behavior, even under linear response assumptions.

The analysis in this study incorporates soil flexibility by introducing a flexible base condition, which contrasts with the conventional fixed-base approach. This modification allows for a more accurate estimation of how the foundation interacts with the ground during dynamic loading. The inclusion of SSI effects helps in assessing the actual demand placed on the structure and provides valuable insights into how this interaction influences the overall structural performance.

Findings from the study reveal that accounting for soil compliance generally leads to a reduction in seismic demand on structural elements, particularly in stiffer building systems. The flexibility of the soil acts to dissipate energy and reduce the intensity of forces transmitted to the structure. This effect is especially noticeable in joints and infill regions, where reduced damage is observed compared to fixed-base models. In summary, the simplified modeling of soil in conjunction with modern analytical tools presents a practical and effective approach for evaluating the seismic performance of buildings, highlighting the importance of including SSI in structural assessments.

M. Mekkia b, S.M. Elachachia, D. Breyssea, M. Zoutat(2016) presented “Seismic behavior of R.C. structures including soil-structure interaction and soil variability effects” This study focuses on the application of performance-based earthquake engineering (PBEE) principles to evaluate and quantify the behavior and risk associated with structures, particularly when Soil-Structure Interaction (SSI) effects are present. A central challenge in this context is accounting for all sources of uncertainty—both aleatory (inherent randomness) and epistemic (lack of knowledge)—throughout the design process. To effectively assess performance and risk, it is essential to understand how these uncertainties in structural, soil, and load

parameters propagate and influence structural responses, especially in relation to defined performance limit states.

The main objective of this research is to develop an approximate yet reliable method to analyze the effects of SSI and determine the impact of key parameters such as the performance point and reduction factor on the system's response. For this purpose, the N2 method is adapted to include nonlinear structural behavior influenced by SSI under seismic loading conditions. The analysis integrates both types of uncertainties and investigates several aspects related to SSI, including the significance of soil properties and the stiffness ratio between the foundation and the surrounding soil.

The findings demonstrate that a structure's seismic response is influenced not only by its inherent dynamic properties and the characteristics of the ground motion but also by the conditions at the base—specifically, the interaction between the soil, foundation, and structure. It is also observed that the largest source of variability in the structural response is due to uncertainties in seismic input and soil characteristics, while variations in structural parameters contribute comparatively less. These insights highlight the necessity of incorporating SSI effects and uncertainty analysis in seismic design to enhance the accuracy and reliability of performance predictions.

METHODOLOGY

This study investigates the impact of Soil-Structure Interaction (SSI) on the seismic performance of a G+20 RCC building located in Seismic Zone V. The methodology involves the detailed modeling of the building and the foundation system with the consideration of three distinct soil layers, using ETABS software. The building is subjected to seismic forces in accordance with IS 1893:2016 for seismic design and wind loads based on the IS 875 (Part 3) code. The study aims to analyze the building's response to these forces while considering the flexibility of the foundation due to soil interaction.

A G+20 RCC building is modeled as a reinforced concrete structure consisting of 20 storeys. The building is designed to withstand vertical loads (dead load, live load) and lateral loads (seismic and wind). The following parameters are incorporated into the model:

Dimensions and Materials: The building has a typical floor plan, with columns, beams, and slabs de-signed according to standard design principles. Material properties used in the model include concrete grade M25 and steel grade Fe500 for reinforcement. The structural components, including beams and columns, are designed to resist the lateral forces imparted by seismic and wind loads.

Load Considerations: The building is subjected to seismic loads according to the seismic response spectrum for Seismic Zone V (as per IS 1893:2016). Additionally, wind loads are applied based on the IS 875 (Part 3) code, where the wind speed is set at 47 m/s to account for high-speed winds typical in the region.

In this study, SSI plays a crucial role in accurately predicting the building's seismic behavior. The build-ing's foundation is modeled with three layers of soil, each with distinct properties that represent the typical soil conditions in the study area. The three soil layers considered are:

- **Layer 1 (0-5 meters):** Soft clay with a low shear modulus and high damping ratio. This soil layer exhibits large deformations under seismic excitation, significantly affecting the building's response.
- **Layer 2 (5-15 meters):** Medium-dense silty sand with moderate shear modulus and damping properties. This layer provides some resistance to deformation but still experiences substantial shaking under earthquake conditions.
- **Layer 3 (15-30 meters):** Dense sand with gravel that provides high shear modulus and low damping. This layer is stiffer and more resistant to seismic motion, providing stability to the foundation system.

Each soil layer is modelled with the following parameters:

- **Shear Modulus (G):** Indicates the soil's resistance to shear deformation, which is crucial for evaluating seismic wave propagation.
- **Damping Ratio:** Represents the energy dissipation ability of the soil, which affects the overall seismic response.
- **Unit Weight:** The density of the soil, influencing the foundation's interaction with the building.

These soil properties are implemented into ETABS, where the foundation is modeled as a flexible base, and the interaction between the soil and the structure is simulated through spring elements that represent the foundation's compliance with the underlying soil.

Both seismic and wind loads are applied simultaneously to evaluate the building's performance under combined loading conditions. The results help assess the structure's response to lateral forces and determine the storey drift, base shear, and displacement for both seismic and wind loads.

The methodology presented here incorporates Soil-Structure Interaction (SSI) to provide a more realistic and accurate seismic and wind load analysis of a G+20 RCC building in Seismic Zone V. By considering three distinct soil layers with varying stiffness and damping properties, the study assesses how soil flexibility influences the building's seismic performance. The comparison of fixed-base and SSI models helps to highlight the significant impact of soil-structure interaction on the building's response to seismic and wind forces. The results of this study provide valuable insights into optimizing the foundation design and improving the overall safety and performance of buildings in high seismic and wind-prone regions.

MODELLING AND ANALYSIS

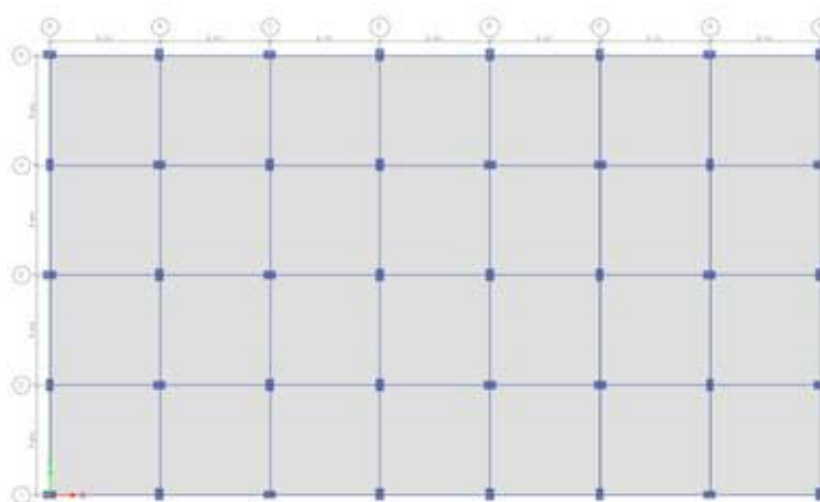


Figure no.1: Plan of Building

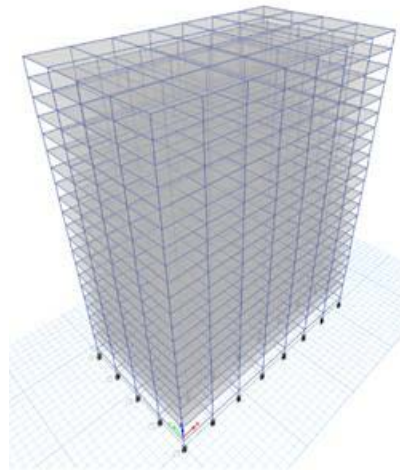


Figure 2: 3D View of Building

Material Properties: Concrete grade: M30, Steel grade: HYSD500

Trial Sizes of elements: Beam- 450X600 MM, Column- 600X900 MM, Slab thickness- 250 MM

Load combinations

a) Strength load combinations-

1.5 (DL + L.L)	1.2 (DL + LL ± EQX)
1.5 (DL ± EQX)	1.2 (DL + LL ± EQY)
1.5 (DL ± EQY)	1.2 (DL + LL ± WLX)
1.5 (DL ± WLX)	1.2 (DL + LL ± WLY)
1.5 (DL ± WLY)	0.9 DL ± 1.5 WLX
0.9 DL ± 1.5 EQX	0.9 DL ± 1.5 WLY
0.9 DL ± 1.5 EQY	

b) Service load combinations

1 (DL + LL)	0.8 DL + 0.8 LL ± 0.8 EQX
1 (DL ± EQX)	0.8 DL + 0.8 LL ± 0.8 EQY
1 (DL ± EQY)	0.8 DL + 0.8 LL ± 0.8 WLX
1 (DL ± WLX)	0.8 DL + 0.8 LL ± 0.8 WLY
1 (DL ± WLY)	

Load Calculations

Dead load and live load calculation on slab (As Per is 875-2015 Part-1&Part-2 clause 3.1 Table 1):

Dead load calculation (from IS 875 part-1)

Dead Load = DL of tiles +DL of mortar + DL of filler material
 = 0.2 + (density of mortar x thickness) + (density of filler x thickness)

Assuming,

Thickness of mortar=25mm

Thickness of filler material=75mm

Filler material=sand

Dead Load = 0.2 + (20.40 x 0.020) + (17.00 x 0.050)
 = 0.2 + 1.258 = 1.458 KN/m² □ 1.5 KN/m²

Sunken slab load calculation -

Dead Load = Light weight filling material + Floor Finish
 = 0.15 x 10 + 1.5 = 3.0 KN/m²

Table no.1: Load on slab

Sr. No.	Slab type	Dead Load (kN/m ²)	Live Load (kN/m ²)
1	Habitual slab	1.5	2
2	Lobby area	1.5	3
3	Sunken slab	3	2
4	Terrace slab	3	2
5	Staircase slab	3	3

Load on beams

Wall load =c/s area x density of wall
 = 0.15 x (3-0.60) x 10 = 3.6 KN/m

Balcony & parapet wall load = 1.5 KN/m

Earthquake Load (IS-1893-Part: 1-2016)

Seismic parameters: The residential building located where seismic is Zone V with factor 0.36. Since it is a residential building, which is having importance factor 1.2. Dual system is considered as a lateral load resisting system in which ductile RC shear walls with RC SMRF with response reduction factor (R) 5 is taken. Project building is located on type B medium stiff soil site.

Design lateral force = $V_b = A_h \times W$ (As per 1893–2016-part 1 clause 7.2.1)

Where,

A_h = Design horizontal acceleration spectrum value as per using the fundamental Natural period Time period

Percentage of imposed load to be considered in seismic weight calculation:

25% for live load up to 3 KN/m² (As per 1893-part 1 clause 7.3.1 table 10)

Wind Load Calculations

Wind loads will be calculated in accordance with IS 875: Part 3.

Project is considered to be located where basic wind speed 47 m/sec with fairly level topography. Mean return period of 50 years is considered for which the k_1 factor will be 1. Since the project building is considered to having some surrounding buildings of sizes up to 10 m in height with or without a few isolated tall structures, hence it will be in terrain category is III.

Design wind speed $V_Z = V_b \times k_1 \times k_2 \times k_3$

V_b = Basic wind velocity for Mumbai = 33 m/s (As per 875 2015-part 3 clause 6.2 annex A)

k_1 = Risk coefficient for a design life of 50 years = 1.0 (clause 6.3.1 table 1 (General building))

k_2 =terrain, height & structure size factor (table: 2 of is 875: part3)

Terrain category = 3

Structure class = C

k_3 = Topography factor = 1.0 for upwind slope < 3

RESULTS AND DISCUSSION

Displacement

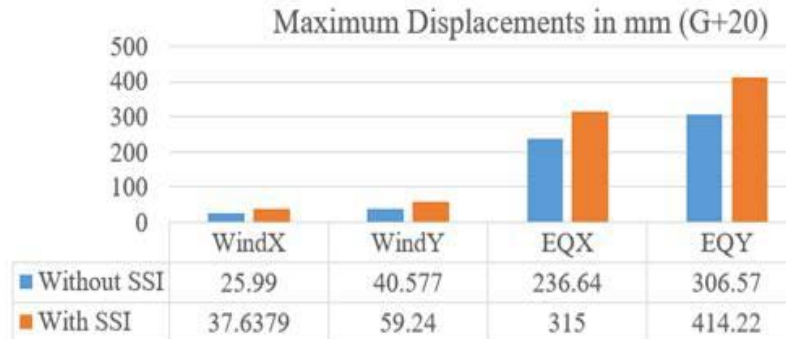


Figure no. 3: Displacement in Building

Lateral displacement of a 60 m-tall G+20 RCC building in Seismic Zone V was evaluated under both wind (47 m/s) and seismic loads, comparing a fixed-base model to one that includes soil structure interaction (SSI). Code limits on deflection are $H/500$ (120 mm) for wind and $H/250$ (240 mm) for earth-quakes. With SSI, wind drift rose from 26 mm to 38 mm in the X direction and from 41 mm to 59 mm in Y—still safely below 120 mm. Under seismic loading, however, SSI increased X direction displacement from 237 mm to 315 mm and Y direction from 307 mm to 414 mm, both exceeding the 240 mm limit. These results demonstrate that SSI substantially amplifies earthquake-induced deformations in tall structures and must be included in design. When predicted deflections surpass code limits, strategies such as increasing structural stiffness, enlarging member sizes, using base isolation, or improving soil properties should be employed to maintain safety and serviceability.

Drift

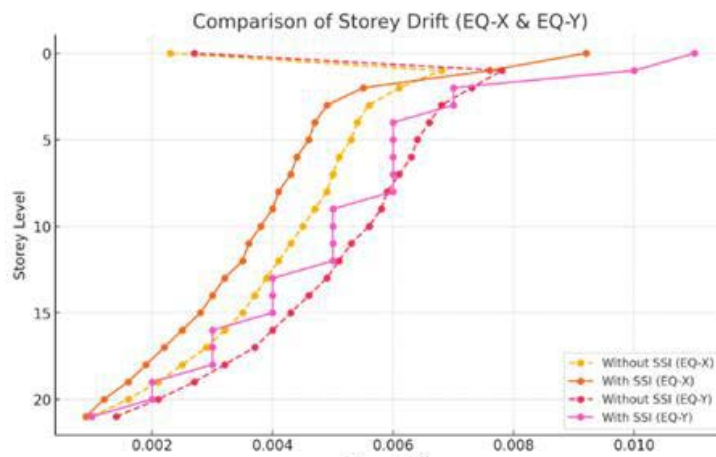


Figure no.4: Drift in Building

Inter storey drift—the relative lateral displacement between successive floors—is a key measure of seismic performance and must not exceed 0.4% of story height (0.012 for a 3 m floor) according to IS 1893. In the fixed base model, drift values rise from the base up to mid height and then taper toward the roof, peaking at the first floor with 0.0068 in the X direction and 0.0078 in the Y direction. When Soil Structure Interaction (SSI) is included, the distribution flattens in the upper stories—since the flexible foundation absorbs some motion—but lower stories and the base experience markedly higher drifts. Specifically, the first floor drifts increase to 0.0076 (EQ X) and 0.010 (EQ Y). At the foundation level, drifts jump from 0.0023/0.0027 (X/Y) without SSI to 0.0092/0.011 with SSI, underscoring how soil compliance concentrates deformation at the base. Although all values remain under the 0.012 limit, the pronounced increase at lower levels demonstrates that neglecting SSI can under predict critical drifts, potentially misleading the design of columns, shear walls, and non structural elements in tall buildings.

Overtuning Moment



Figure no. 5: Overtuning Moment in Building

The overturning moment, an indicator of a structure’s tendency to tip under lateral loads—was compared for a G+20 RCC building with and without SSI across four load cases (EQ X, EQ Y, WL X, WL Y). Under seismic action in the X direction, the base moment falls from 13.87×10^6 kN•m (fixed base) to 11.72×10^6 kN•m when SSI is modeled, a reduction of

about 15.5%. In the Y direction, it decreases by roughly 9% from 10.39×10^6 kN•m to 9.45×10^6 kN•m. In contrast, wind induced overturning moments (140,784 kN•m in X and 201,577 kN•m in Y) remain unchanged regardless of SSI.

This reduction under seismic loading stems from the soil’s added flexibility: as the foundation springs and deforms, part of the earthquake’s energy is dissipated through soil movement and foundation rotation rather than being transferred entirely into the superstructure. Wind loads, being lower in magnitude and applied more gradually, do not engage this dynamic interaction, so their overturning effects are essentially the same with or without SSI.

Base Shear

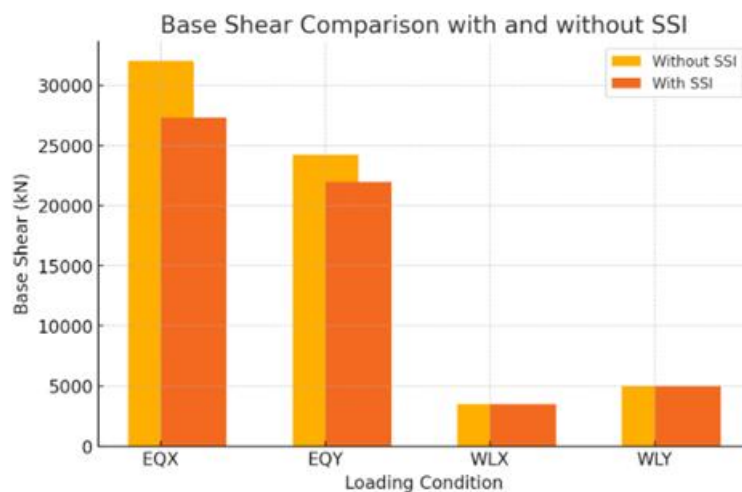


Figure no. 6: Base Shear in Building

Base shear defined as the total lateral force resisted at the foundation—is a key design parameter for both seismic and wind loading. In this study, we compared base shear in the X and Y directions for a G+20 RCC building modeled both with a rigid base and with soil-structure interaction (SSI).

When SSI is included, seismic base shear decreases notably. In the X direction, it falls from 32 055.6 kN (fixed base) to 27 342.8 kN—a drop of about 14.7%. In the Y direction, it declines from 24 218.3 kN to 22 012.1 kN, roughly a 9.1% reduction. This lowering of seismic forces occurs because the flexible soil foundation lengthens the building’s natural period, shifting the structure into a lower-acceleration range on the response spectrum. As a

result, even though lateral displacements and drifts grow with SSI, the peak seismic load demands diminish. Expressed relative to the building's weight, the seismic base shear ratio in X falls from 6.9% to 5.88%, and in Y from 5.21% to 4.74%.

By contrast, wind-induced base shear remains unchanged by SSI—3 509.47 kN in the X direction and 5 024.92 kN in the Y direction—because wind loads are applied as static or slowly varying pressures and are largely insensitive to foundation flexibility.

Discussion

The incorporation of Soil-Structure Interaction (SSI) significantly influences the seismic and wind response behavior of high-rise buildings, particularly those located in high seismic zones like Zone V. In this study, a G+20 reinforced concrete (RCC) building was analyzed to assess the effects of SSI under lateral loading conditions, specifically earthquake and wind forces. The primary response parameters evaluated include lateral displacement, storey drift, overturning moment, and base shear, both with and without the inclusion of SSI.

The study shows that Soil-Structure Interaction (SSI) has a notable impact on the seismic and wind performance of a G+20 RCC building in Seismic Zone V. When SSI is considered, lateral displacements under seismic loads increase significantly, often exceeding permissible limits. For instance, in the EQ-Y direction, displacement increased from 306.57 mm to 414.22 mm. This increase is due to the added flexibility from the soil, which lengthens the natural period of the building, leading to higher deformation during earthquakes. Under wind loads, however, displacements remain well within limits, even with SSI.

Storey drift patterns also change with SSI. Without SSI, drift follows an inverted V-shape—peaking at mid-height. With SSI, drift increases at lower levels and flattens out at upper levels. Still, all drift values remain below the allowable limit of 0.012, though SSI pushes the structure closer to the threshold, especially near the base.

Overturning moments due to seismic loads decrease when SSI is included—by about 15.5% in the EQ-X direction and 9% in EQ-Y—thanks to energy absorption and rotational flexibility at the base. Wind-induced overturning moments remain unchanged since wind loads don't significantly excite the soil-structure system.

Finally, base shear under seismic loading reduces by 14.7% (EQ-X) and 9.1% (EQ-Y) with SSI, again due to the increased time period. Wind base shear, however, remains constant in both models.

In summary, the results affirm that SSI plays a crucial role in modifying the seismic response of tall buildings. While it leads to increased displacements and storey drifts—especially at lower levels—it also reduces base shear and overturning moments due to energy absorption through the soil. The findings stress the importance of incorporating SSI in structural analysis to ensure a more accurate prediction of building behavior under lateral loads, especially in seismic-prone areas. Neglecting SSI may result in unsafe or overly conservative designs, depending on the response parameter considered.

CONCLUSION

- **SSI Significantly Affects Seismic Response:** The inclusion of SSI leads to an increase in lateral displacements and inter-storey drifts, especially under seismic loading conditions.
- **Lateral Displacements Increase with SSI:** Seismic displacements exceeded the permissible limits when SSI was considered, particularly in the EQ-Y direction, indicating a more flexible and deformable structural behaviour.
- **Wind-Induced Displacements Remain within Limits:** Under wind loads, even with SSI, lateral displacements stayed well within the permissible range, showing that SSI has a less pronounced effect under wind actions.
- **Storey Drift Patterns are altered by SSI:** Without SSI, the drift follows a conventional inverted V-pattern, while with SSI, the drift becomes more concentrated at lower storeys, highlighting increased flexibility at the foundation level.
- **All Drift Values Stay Below Permissible Limit:** Although SSI increases drift values, they remain within the acceptable range as per IS 1893 (Part 1): 2016 guidelines, ensuring structural safety.

- **Reduction in Seismic Base Shear:** SSI causes a noticeable reduction in base shear values approximately 14.7% in EQ-X and 9.1% in EQ-Y—due to an increased time period and altered dynamic response.
- **No Impact of SSI on Wind Base Shear:** Wind base shear values remain unchanged with or without SSI, suggesting that soil flexibility does not significantly influence wind-induced forces.
- **Overtopping Moment is Lower with SSI:** The seismic overturning moments decreased notably with SSI (15.5% in EQ-X and 9% in EQ-Y), indicating partial energy dissipation through soil deformation.
- **Soil Flexibility Influences Structural Behavior:** The increased flexibility from SSI modifies the stiffness and dynamic properties of the structure, which must be accounted for in seismic design, especially for high-rise buildings.
- **Importance of Considering SSI in Design:** Ignoring SSI may lead to unsafe or overly conservative designs. Its inclusion ensures more realistic results and better-informed structural design decisions for buildings in high seismic zones.

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