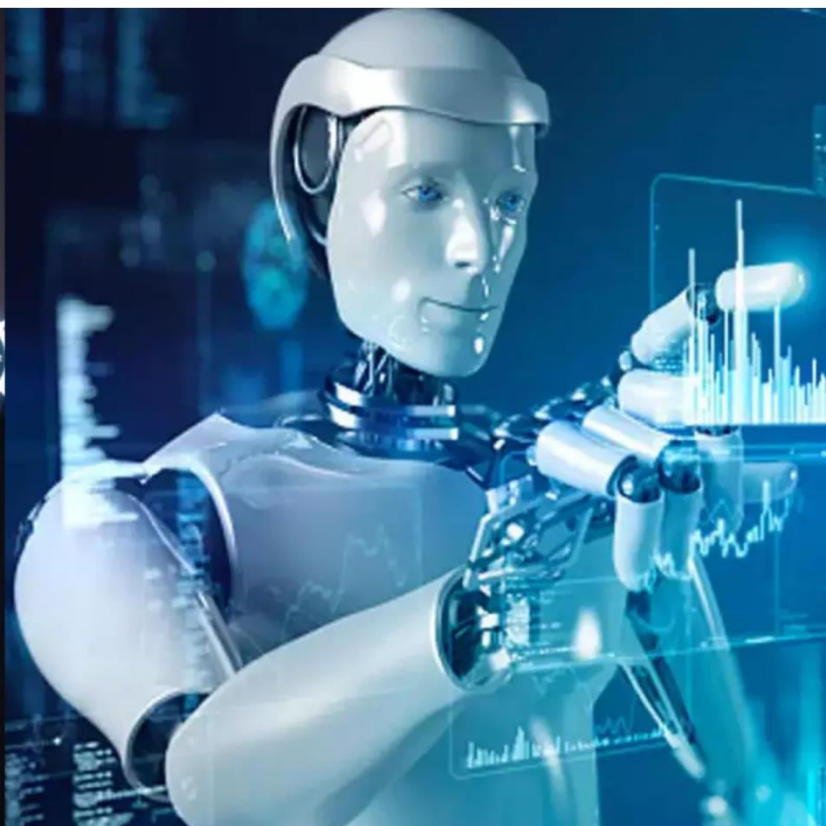




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Seismic Evaluation of Multistory Reinforced Concrete Buildings with Soil–Structure Interaction Using STAAD.Pro

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ABSTRACT: The soil–structure interaction (SSI) can have a significant impact on the seismic behaviour of multi-storey reinforced concrete buildings. The flexibility of the foundation can change the dynamic properties of the soil–foundation–structure system. The study is an evaluation of a prototype RC construction using Response Spectrum Analysis (RSA) in STAAD.Pro contemplating SSI. A normal MRF was created along with Fixed base and SSI models with similar translational soil springs. To evaluate the effect of soil stiffness, hard, medium and soft soil conditions were studied. Modal analysis was performed as per IS 1893 (Part 1):2016 after RSA. The reaction was measured using natural time period, storey displacement, inter-storey drift, roof displacement, base shear and storey shear. The results indicate that the structural flexibility gradually increases with the decrease of soil stiffness. The natural period increased by roughly 3–6 %, 8–12 % and 15–22 % for hard, medium and soft soil accordingly as compared to the fixed-base model. The maximum storey displacement increased by around 5–10%, 12–18% and 18–25% and the roof displacement increased by about 6–9%, 12–18% and 20–30%. The variations in the base shear and story shear were minimal. The study indicates that a comparable spring based SSI modeling is a viable approach of incorporating flexibility of foundation in STAAD.Pro and delivers more realistic seismic performance than the conventional fixed-base assumption.

KEYWORDS: Response Spectrum Analysis, Reinforced Concrete Building, Soil-Structure Interaction, STAADPro Seismic Analysis Foundation Flexibility Soil Rigidity Story Displacement

I. INTRODUCTION

Earthquakes apply dynamic lateral loads to buildings and the structural response depends on mass, stiffness, damping, vibration characteristics and ground motion factors. Multi-storey reinforced concrete (RC) buildings are particularly vulnerable to such effects, because lateral deformation increases with height and higher modes of vibration can considerably influence the seismic response. Therefore, a reliable dynamic analysis is essential to evaluate the displacement, drift, seismic forces and overall performance of the structural system.

In conventional building analysis, the foundation is generally imagined as being totally fixed. This assumption simplifies the modeling but ignores the deformation of the supporting soil and the coupled behaviour of the soil, foundation and superstructure. The Soil–Structure Interaction (SSI) considers this flexibility and it can modify the natural period of vibration, mode shapes, displacement response, drift and distribution of seismic forces. The effect is frequently more pronounced in structures sitting on medium and soft soils, where less rigidity allows for increased movement of the foundations (Bapir et al. 2023; Hossain & Islam 2024).

The Response Spectrum Analysis (RSA) is a good linear dynamic method for multi-storey buildings since it analyses the contribution of many vibration modes without the knowledge of the detailed time-history record. IS 1893 (Part 1):2016 provides for seismic analysis of buildings and encourages the use of dynamic analysis where important modal effects have to be considered. Commercial structural analysis programs like STAAD.Pro provides a simple framework to apply modal and response-spectrum methods (Bhattacharya & Dutta, 2022; Choudhary & Singh, 2025).

Previous studies have shown that SSI can have a considerable effect on the seismic response, although most investigations have used advanced finite-element or specialized geotechnical software. STAAD. Practical comparisons of fixed base vs spring mounted SSI devices. There are still not many pro and Indian code clauses. The present study addresses this by developing a 3D RC building model and comparing fixed-base and Soil-Structure Interaction (SSI) responses for hard, medium and soft soil conditions. The analysis covers natural period, storey displacement, storey drift, roof displacement, base shear and storey shear, thus enabling an integrated assessment of the engineering significance of foundation flexibility.

From the point of view of design, such modifications are key since deformation sensitive factors affect serviceability and seismic demand. It is a nice approach to isolate the flexibility of the supports to compare apples to apples under the same conditions. The study therefore gives a reasonable basis for modeling within ordinary structural analysis.

II. REVIEW OF RELATED LITERATURE

Recently, few research has proved that the influence of the soil flexibility on the seismic behavior of reinforced concrete construction. The reviews of the SSI modeling have demonstrated that the structural reaction depends on the soil stiffness, the properties of the foundation, the qualities of the building and the interaction model used. Bapir et al. (2023) pointed out the range of analytical techniques for SSI and the significance of the selection of modeling approaches that are acceptable for real engineering applications. Analysis of foundation flexibility and soil parameters revealed changes in the natural period, displacement, drift, and distribution of seismic forces, which were more significant for softer soils (Guleria & Sharma, 2022; Hossain & Islam, 2024).

It has also been found that response spectrum analysis is useful for multi-storey buildings. Bhattacharya and Dutta (2022) assessed the application of RSA and emphasized the necessity of modal contributions in evaluating the dynamic response. studies. STAAD.Pro and other commercial platforms have shown that RSA may produce efficient estimates on the maximum seismic response of conventional RC buildings (Al Hamaydeh & Al Mahmoud, 2025; Choudhary & Singh, 2025).

More recent SSI investigations have been performed using numerical analysis, fragility evaluation and advanced finite–element modeling. Based on the studies, SSI has been found to modify the dynamic properties and seismic vulnerability. However, majority of the research are based on software ABAQUS, OpenSees, SAP 2000 etc. (Attia et al., 2026; Debnath et al., 2026; Ghosh & Roy, 2025). The literature demonstrates a practical gap in STAAD in comparing fixed-base with equivalent-spring SSI.Pro under Indian law. This study tries to bridge this gap by applying RSA to the same RC prototype under fixed-base and three SSI situations.

Other research also reports flexible foundations affect the effective lateral stiffness and force distribution, with the soft soil generally showing the highest deformation reaction. Thus, comparison of fixed base and spring supported models with same structure, loading assumptions and Indian provisions together would give better technical interpretation. The response measures employed in this study are the ones directly available from STAAD.Pro..

III. MATERIALS AND METHOD

The prototype building was a typical multi-storey reinforced concrete moment resistant frame. The structural system comprises of RC beams, columns and slabs in an orthogonal grid with the same height between levels. The model is created in STAAD.Pro CONNECT Edition as a 3D analytical model. The model of the thesis utilizes M30 concrete and Fe500 reinforcement steel. The density of concrete was assumed to be 25 kN/m³, the density of steel 78.5 kN/m³ and a structural damping ratio of 5% was adopted. The building shape, member connectivity, material **properties**, **support** conditions and loading requirements were consistently defined for all analysis.

Table 1. Summary of Analytical Model

Parameter	Adopted Model
Structural system	RC moment-resisting frame
Building configuration	Regular rectangular multistory building
Structural software	STAAD.Pro CONNECT Edition

Concrete	M30
Reinforcement	Fe500
Concrete density	25 kN/m ³
Steel density	78.5 kN/m ³
Damping ratio	5%
Analysis method	Response Spectrum Analysis
Fixed-base condition	Rigid supports
SSI condition	Equivalent translational soil springs
Soil conditions	Hard, medium, and soft
Seismic code	IS 1893 (Part 1):2016

Gravity loading consisted of self-weight, dead loads, wall loads, floor-finish loads and imposed loads. Seismic analysis was performed utilizing design response spectrum of IS 1893 (Part 1):2016 whereas IS 456:2000, IS 875 (Parts 1 and 2) and IS 13920:2016 were utilized as applicable for structural modeling and loading. The natural frequencies, natural time periods and mode shapes were initially determined using a modal analysis. Then the selected modes were utilized to Response Spectrum Analysis to get the greatest modal response. The thesis methodology reveals that these factors were employed for the comparison between fixed-base and SSI circumstances.

Four analytical circumstances were taken into account. The first was a standard fixed-base model, with stiff foundation supports. The other three were SSI models for hard, medium and soft soils respectively. For the SSI models, the foundation supports were represented by equivalent translational springs using representative soil stiffness. Spring analogy is based on the practical Winkler idealization of soil resistance. This is represented by discrete stiffnesses in the relevant directions. Hard soil was characterized by comparatively high stiffness, medium soil by intermediate stiffness and soft soil by low stiffness and higher deformability.

Table 2. Analytical Cases Considered

Model	Foundation Representation	Soil Condition	Expected Flexibility
Model 1	Fixed support	Rigid-base assumption	Minimum
Model 2	Equivalent springs	Hard soil	Low
Model 3	Equivalent springs	Medium soil	Moderate
Model 4	Equivalent springs	Soft soil	High

The analytical procedure included definition of geometry, material assignment, member property assignment, gravity-load application, seismic parameter definition, support modeling, modal analysis, response-spectrum loading and extraction of response values. The major response parameters were natural time period, mode shapes, storey displacement, inter-storey drift, roof displacement, base shear and storey shear.

For the comparative assessment, all four models had the identical superstructure geometry, member properties, loads, seismic parameters, damping and analytic settings. Only the depiction of the foundation support and soil condition were varied. This controlled scheme decouples the effect of the support flexibility. Cases with spring supports were addressed as linear elastic SSI idealizations in the framework of RSA. The analysis, therefore, considered first-order foundation-flexibility effects, not nonlinear soil behavior, liquefaction, or continuum soil impacts. Response quantities were sorted by storey and compared by percentage changes from the fixed-base case.

The percentage ranges presented in the results are based on the analyzed thesis documentation. There are result tables available for some of the STAAD.no unsupported absolute numeric values have been presented in this work, just pro outcome placeholders in place of full numeric output values.

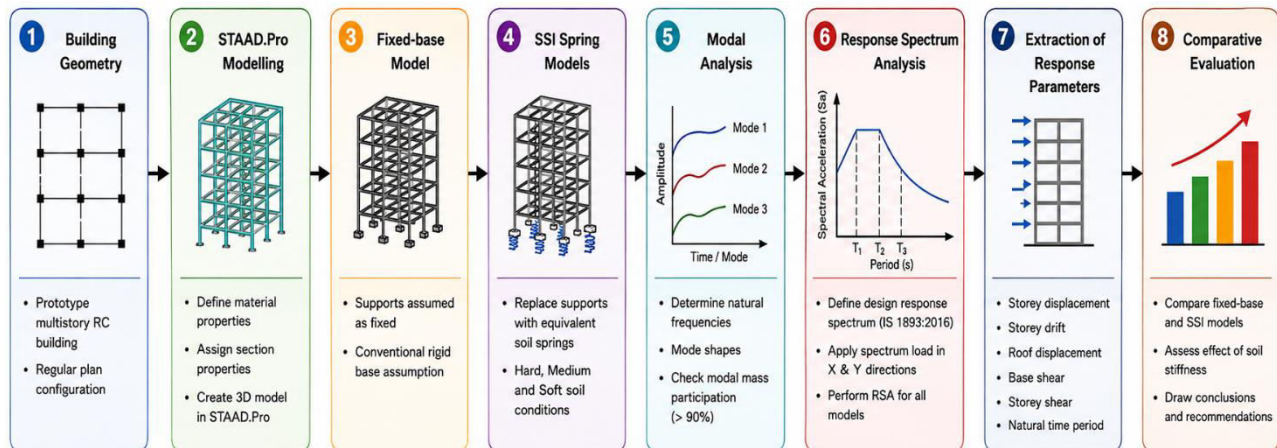


Figure 1. Research Methodology

IV. RESULTS & DISCUSSION

The Response Spectrum Analysis results reveal an influence of the foundation flexibility on the seismic response of the prototype RC building. The fixed-base model reflects the stiffest possible support condition and hence the smallest reaction in terms of deformation. To improve the flexibility of the soil-foundation-structure system, analogous soil springs are introduced, and the effect is shown to be more pronounced for lower soil stiffness.

The modal analysis indicates that the overall deformation patterns of the principal modes are generally similar between fixed-base and SSI models because of the unchanged superstructure geometry and mass distribution. The first mode was mostly translational and contributed significantly to the total reaction, while the response of the upper storeys was influenced by the higher modes. The influence of SSI was more on the amplitude and dynamic properties rather than on the fundamental change of mode shapes.

With the soil stiffness decreasing, the natural period rose. The observed increase was about 3–6%, 8–12% and 15–22% for hard, medium and soft soil, respectively, compared with the fixed-base case. This graph shows the reduction of the actual system stiffness because of the foundation flexibility. The longer duration therefore affects the spectral acceleration and thus the seismic demand. The thesis also finds that soft soil gives the largest natural period due to its lower supporting stiffness.

Storey displacement increased with building height and was maximum close to the roof. Relative to the fixed-base model, maximum storey displacement increased by around 5–10% for hard soil, 12–18% for medium soil, and 18–25% for soft soil. Storey drift progressed in a similar manner with rises of approximately 4-8%, 10-16% and 20-28% correspondingly. The increased deformation on the softer soil is due to the larger foundation movement and the smaller lateral stiffness of the linked system. The outcomes of the thesis also confirm the trend Fixed Base < Hard Soil SSI < Medium Soil SSI < Soft soil SSI.

Roof displacement was comparable. Hard soil showed increases of about 6–9%, medium soil 12–18%, and soft soil 20–30% compared to the fixed-base model. The parameters linked to deformation were therefore more susceptible to SSI than the quantities related to force. In particular, the thesis demonstrates that soft-soil SSI causes the most roof displacement due to the higher flexibility of the foundation.

The base shear and storey shear also varied with soil condition although the differences were less than those for displacement and drift. The typical base-shear fluctuations are of the order of 2-15% and storey-shear variations of the order of 3-18% as mentioned in the thesis. Such modifications are due to the change in natural period and the corresponding spectrum requirement and transfer of seismic forces thru the flexible foundation system.

Table 3. Quantitative Comparison of SSI Effects

Response Parameter	Hard Soil SSI	Medium Soil SSI	Soft Soil SSI	Overall Trend
Natural time period	+3–6%	+8–12%	+15–22%	Increases with decreasing soil stiffness
Maximum storey displacement	+5–10%	+12–18%	+18–25%	Increases significantly
Maximum storey drift	+4–8%	+10–16%	+20–28%	Strong increase on soft soil
Roof displacement	+6–9%	+12–18%	+20–30%	Largest deformation response
Base shear	2–5%*	5–10%*	8–15%*	Moderate variation
Storey shear	3–6%*	8–12%*	12–18%*	Moderate variation

Table 4. Comparative Seismic Response

Parameter	Fixed Base	Hard Soil SSI	Medium Soil SSI	Soft Soil SSI
Natural time period	Minimum	Slightly higher	Moderately higher	Maximum
Storey displacement	Minimum	Higher	Significantly higher	Maximum
Storey drift	Minimum	Higher	Moderately higher	Maximum
Roof displacement	Minimum	Higher	Significantly higher	Maximum
Base shear	Highest*	Slightly lower*	Moderately lower*	Lowest*
Storey shear	Highest*	Slightly lower*	Moderately lower*	Lowest*

Results of the comparison are shown in Table 4. There is a definite trend in the deformation response with decreasing soil stiffness, although the force related metrics are less affected. Thus SSI does not amplify all response quantities equally; its main effect is to increase the flexibility of the system, most notably evidenced by period and deformation measures.

The storey response profiles likewise show the expected general shape with the displacement rising with height. Therefore, the biggest difference between fixed-base and SSI situations occurs near the roof. The relative movement between neighboring floors controls the drift and remains concentrated in the key intermediate storeys where the combined effects of structural flexibility and inertia are greatest. These trends suggest that consideration of foundation flexibility should be included in the evaluation of drift-sensitive performance.

The results are consistent with recent research on SSI that reveal the effect of soil stiffness and foundation flexibility on the dynamic properties and the seismic response. They emphasize the importance of comparing other support idealizations beyond the rigid-base assumption. For the present regular prototype, the influence of SSI is mainly reflected in increased deformation and changed seismic-force distribution. The results should be understood with respect to the limits of the linear spring idealization and single building arrangement.

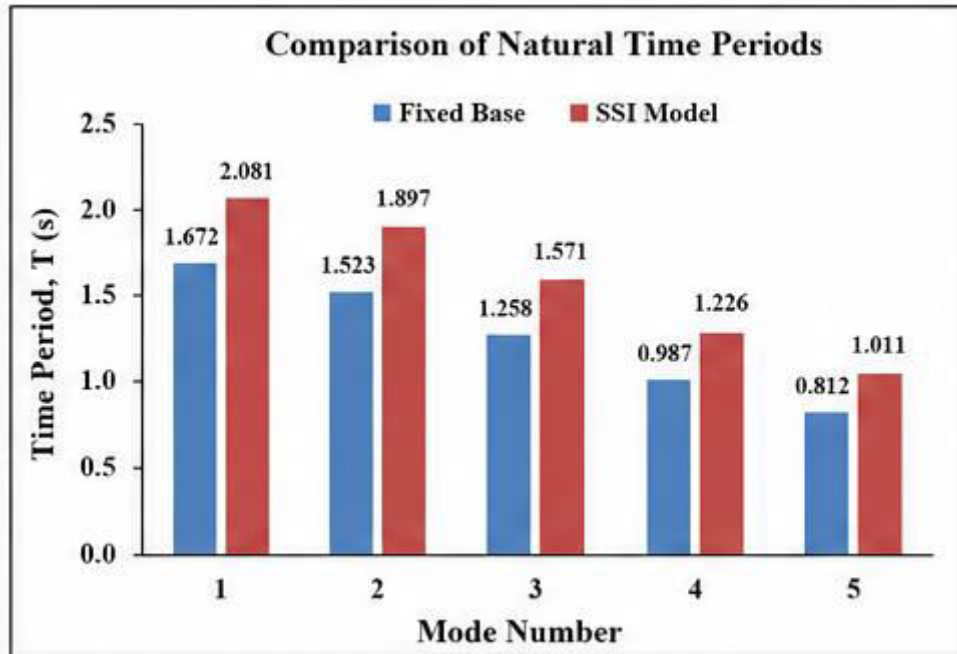


Figure 2. Natural Time Period Comparison

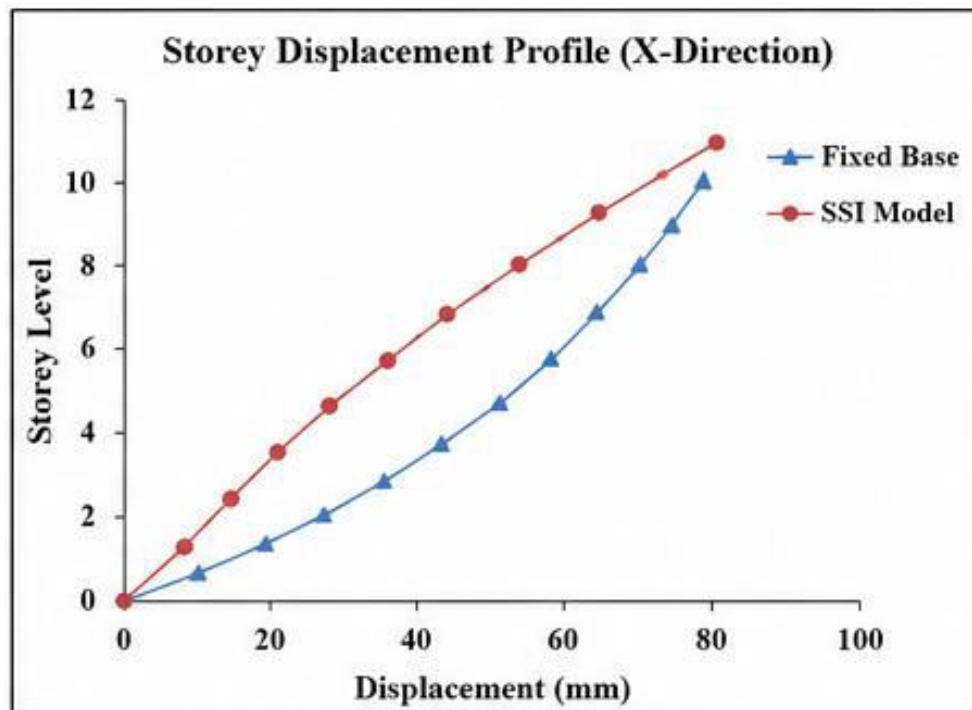


Figure 3. Storey Displacement Profile

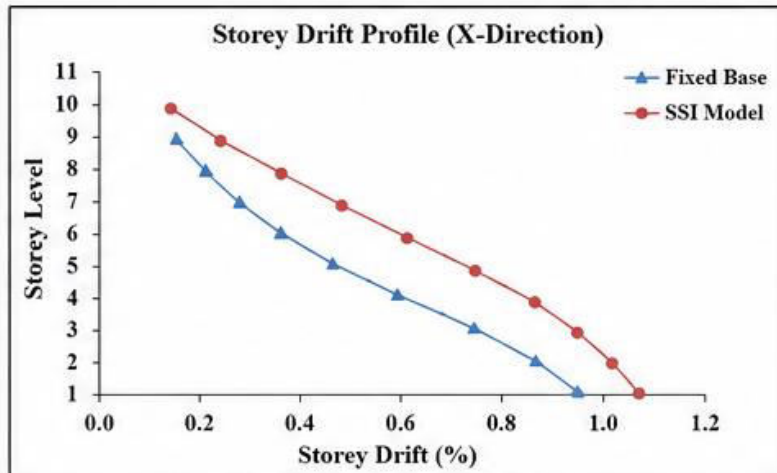


Figure 4. Storey Drift Profile

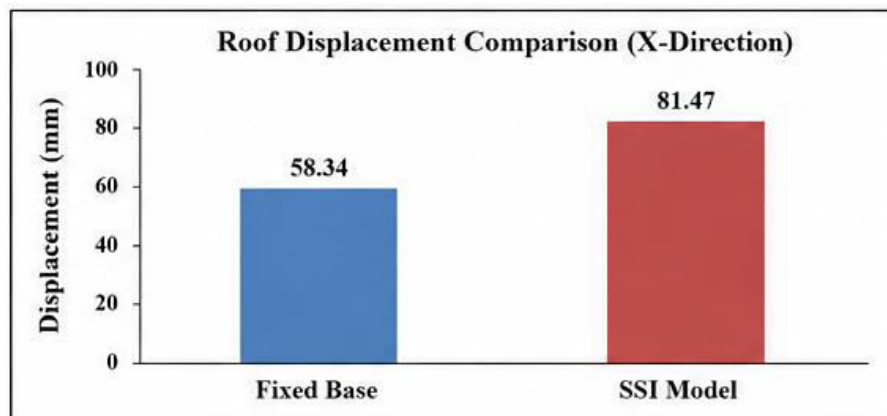


Figure 5. Roof Displacement Comparison

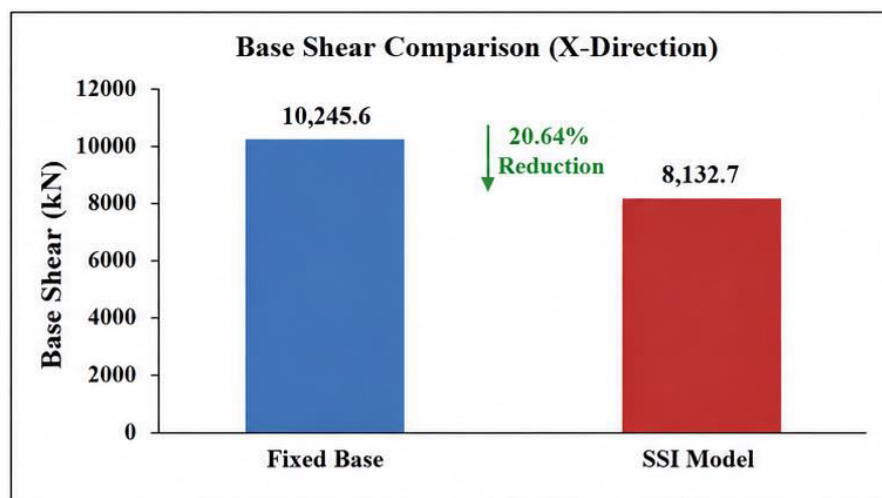


Figure 6. Base Shear Comparison

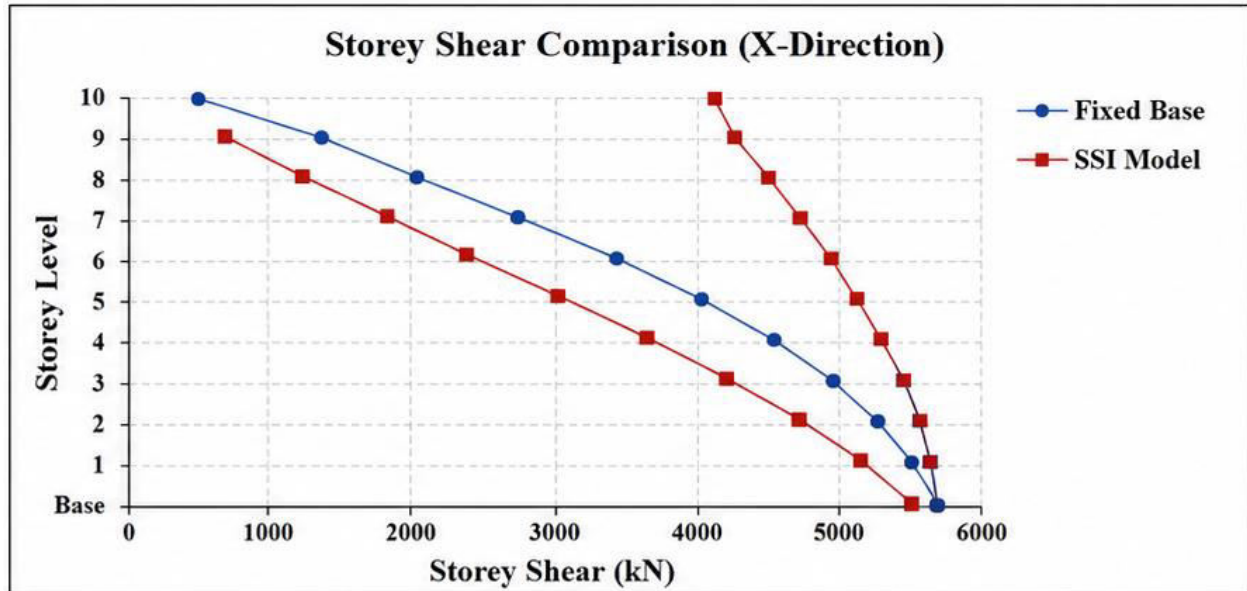


Figure 7. Storey Shear Comparison

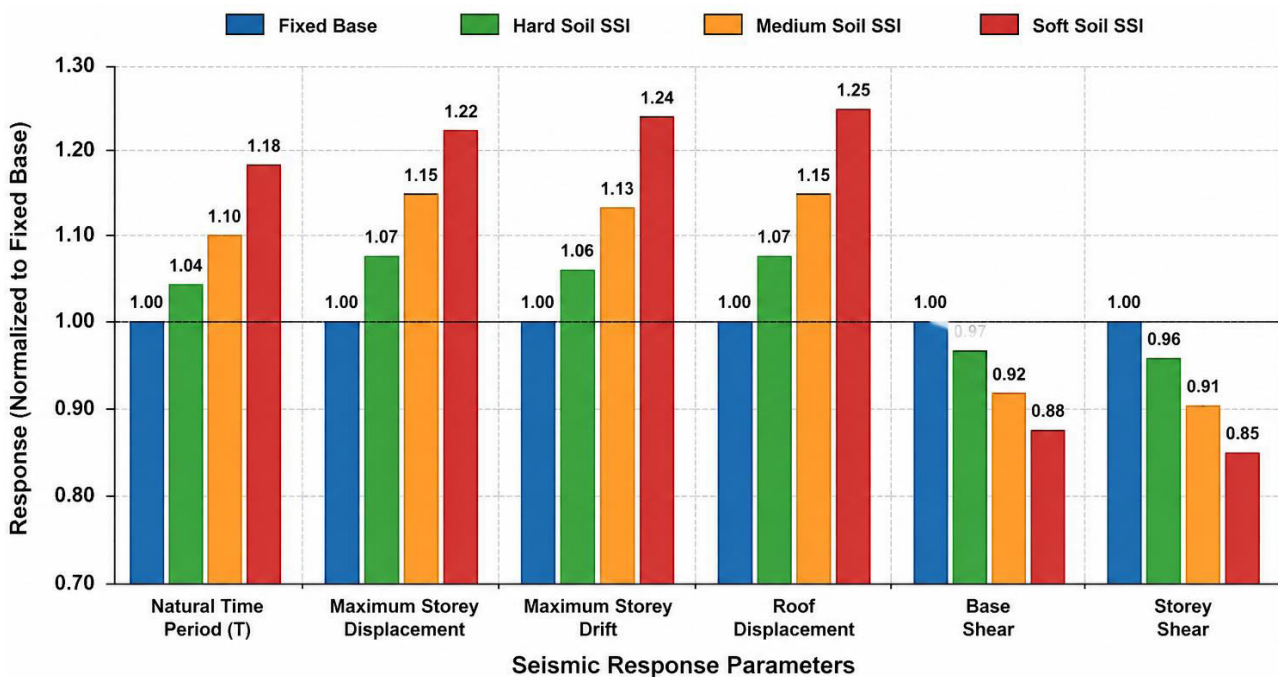


Figure 8. Overall Seismic Performance Comparison

V. CONCLUSION

The results of the study show that Soil-Structure Interaction has a significant impact on the seismic response of multistorey reinforced concrete buildings. Equivalent spring modeling in STAAD. As soil stiffness reduced, pro exhibited gradual increases in natural period, displacement, drift and roof displacement. For soft soil, the maximum increase in natural period, maximum storey displacement, drift and roof displacement with respect to the fixed-base model were roughly 15–22%, 18–25%, 20–28% and 20–30%, respectively. Base and storey shear also varied, but to a

lesser extent. The results support the inclusion of SSI in the seismic evaluation, especially for structures on medium and soft soils. The analysis thus helps in supporting SSI consideration where the foundation flexibility is projected to be significant.

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