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Influence of Site Class on the Dynamic Response of Regular Buildings Considering Soil-Structure Interaction

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Abstract: Throughout history, many buildings have suffered significant damage during major earthquakes. Traditionally, such damage has been extensively analyzed from a structural perspective, assuming a fixed-base condition as a valid approach for lightweight structures built on relatively stiff soil. Under these assumptions, various failure patterns have been identified. However, earthquake damage indicates that a structure's seismic performance is not only influenced by the superstructure's response but also by the behavior of the foundation and the underlying soil. This highlights the importance of considering soil–structure interaction (SSI), as the overall performance of a structure can be affected by the earthquake's characteristics, its propagation path, and the nonlinear behavior of the soil. The soil–structure interaction (SSI) phenomenon is inherently complex; it involves a modification of the incident ground motion due to the dynamic response of the structure. As a result, the motion at the soil–structure interface differs from the free ground motion. This study aims to demonstrate the influence of soil–structure interaction on the behavior of regular mixed structures (frames with shear walls). The response of the structure studied is first evaluated by considering the hypothesis of perfect base fixity (classical model). In the second model (soil–structure interaction model), the soil–structure coupling is taken into account by modeling the soil reaction using springs. Numerical simulations were performed using four types of response spectra corresponding to different site classes, as defined by the Algerian seismic code (RPA 2003).

Keywords: Site class, Soil–structure interaction, Numerical analysis, Dynamic response

Introduction

Since the devastating El Asnam earthquake in 1980, extensive research efforts have been devoted to mitigating the seismic effects on building structures in Algeria and elsewhere. The Algerian seismic design code, RPA99 (version 2003), classifies construction sites into four soil types according to their dynamic properties. Each soil class is associated with a specific elastic response spectrum, determined by both the site characteristics and the dynamic behavior of the structure being analyzed.

The intensity of ground shaking experienced during an earthquake at a particular location largely depends on the nature of the soil and local site conditions. Consequently, it is crucial to adapt the selected response spectrum to the site-specific soil profile and seismic environment. Furthermore, in several engineering contexts, especially for medium and high-rise buildings, the Soil-Structure Interaction (SSI) phenomenon must be considered. This complex interaction reflects a modification of the free-field ground motion caused by the dynamic response of the structure itself, resulting in a non-identical motion at the soil–foundation interface compared to the unperturbed ground motion (Attia & Hadji, 2022; Bapir et al., 2023).

Recent research has demonstrated that the inclusion of SSI can significantly alter a structure's dynamic properties such as its natural frequency, damping ratio, and base shear-depending on the stiffness and shear-wave velocity (V_{s30}) of the soil (Ali et al., 2023; Dawood et al., 2024). Some studies have even reported that SSI effects can be beneficial or detrimental, depending on the resonance between soil and structure (Bapir et al., 2023). In the Algerian context, field investigations using ambient vibration data (Issaadi et al., 2022) have further confirmed the importance of accurately characterizing soil conditions and liquefaction potential in regions such as the Chelif Basin, where soft soils can amplify seismic waves. These findings highlight the need to incorporate SSI analysis into modern seismic design practices and to refine the RPA 2003 site classification system based on recent empirical and numerical insights.

The present study aims to investigate the influence of SSI on the seismic behavior of a regular mixed structure (frames with shear walls). In the first modeling approach, the structure is assumed to be perfectly fixed at the base (conventional fixed-base model). In the second approach, the soil–structure coupling is represented through spring elements simulating soil flexibility and damping. Numerical simulations were performed using the four site-specific response spectra defined in the RPA 2003 code, enabling a comparative analysis of the dynamic response across various soil conditions.

Behaviour of Buildings under Seismic Excitation

Earthquakes do not act as conventional external loads but rather induce stresses in structures through dynamic ground motion. The resulting seismic excitation is transmitted from the ground to the structure's foundation and subsequently throughout the structural system via inertial forces. In typical buildings, the global stiffness and damping characteristics are nonlinear and depend on the magnitude of deformation. These deformations may be predominantly of the bending (flexural) type in wall systems or of the shear type in frame structures (Figure 1) (Priestley et al., 2007; Fardis, 2009). (Figure 1).

During seismic shaking, inertial forces develop within structural elements as a reaction to the imposed ground accelerations. These forces arise from the interaction between individual members and their connecting joints, which transfer loads through shear, moment, and axial actions. Consequently, the inertial forces in any element cannot exceed the strength capacity of its connections; however, the associated deformations may become excessively large once the material yields or the connections lose stiffness. When this occurs, plastic instability can develop, potentially leading to progressive damage or global collapse (Paulay & Priestley, 1992; Alavi & Krawinkler, 2004; Ghosh et al., 2020).

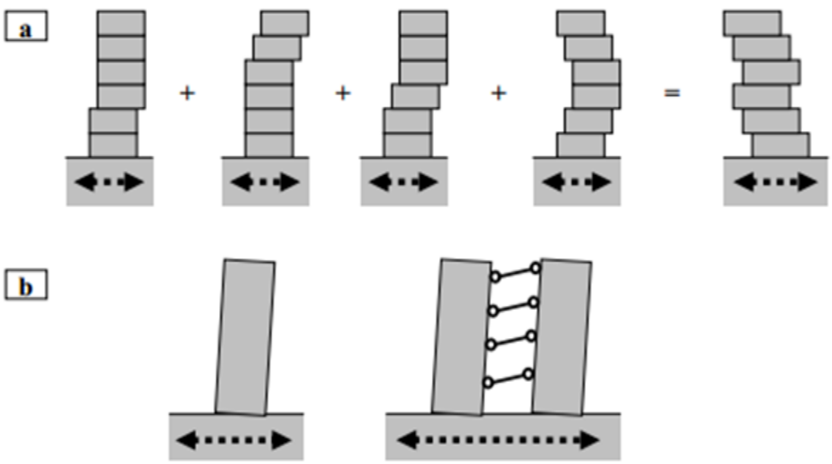

Figure 1. Behavior of structures under seismic excitation:(a) Shear response of moment-resisting frame systems). (b) Bending (flexural) response of load-bearing shear wall systems. (Bapir et al., 2023)

Soil–Structure Interaction Under Seismic Loading

Soil–Structure Interaction (SSI) refers to the mutual influence between a structure, its foundation, and the supporting soil during seismic excitation. When seismic waves propagate through the ground, they induce motion in the soil that, in turn, affects the structure resting upon it. Conversely, the inertial response of the structure exerts additional stresses and displacements back onto the soil. This two-way coupling process modifies the overall dynamic behavior of the soil–foundation–structure system (Awchat, Mallick, & Kanaujia, 2022; Bapir, Abrahamczyk, Wichtmann, & Prada-Sarmiento, 2023).

During an earthquake, the ground motion reaching the foundation is not identical to the free-field ground motion because the foundation alters it through kinematic interaction. Simultaneously, the oscillating superstructure imposes additional inertial interaction forces on the foundation and the surrounding soil. These two phenomena occur together, and the resulting system response differs significantly from that obtained by assuming a rigid or fixed-base condition (Camayang, Padilla, De La Cruz, & Bersamina, 2025). Therefore, a realistic seismic analysis must consider both effects to accurately estimate displacements, base shear, and internal forces.

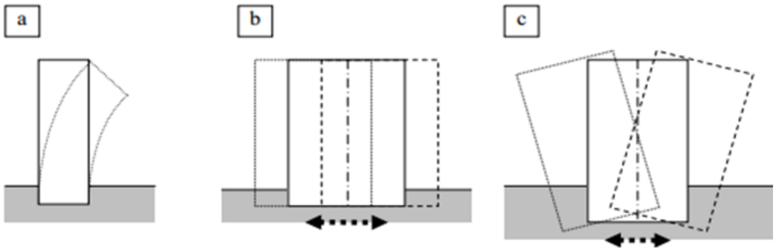

Figure 2. Soil-structure interaction: a) Without ISS, flexible building and soil with very good mechanical strength. b) Without ISS, rigid building and soil with very good mechanical strength. c) With ISS, rigid building and soil with low or medium mechanical strength.

Mathematical Representation

A simplified model of SSI can be expressed as a two-degree-of-freedom (2-DOF) system in which the superstructure and the foundation-soil subsystem are represented by lumped masses, springs, and dashpots. The governing equations of motion can be written as:

$$\begin{pmatrix} m_s & 0 \\ 0 & m_f \end{pmatrix}\begin{pmatrix} \ddot{u}_s \\ \ddot{u}_f \end{pmatrix}\begin{pmatrix} c_s + c_f & -c_f \\ -c_f & c_f \end{pmatrix}\begin{pmatrix} \dot{u}_s \\ \dot{u}_f \end{pmatrix} + \begin{pmatrix} k_s + k_f & -k_f \\ -k_f & k_f \end{pmatrix}\begin{pmatrix} u_s \\ u_f \end{pmatrix} = \begin{pmatrix} 0 \\ m_f \ddot{u}_g \end{pmatrix} \quad (1)$$

where:

m_s and m_f are the masses of the superstructure and the foundation-soil subsystem, respectively

u_s and u_f are the relative displacements of the superstructure and foundation,

k_s and k_f represent the stiffness of the superstructure and soil springs,

c_s and c_f are the corresponding damping coefficients,

$\ddot{u}_g$ is the free-field ground acceleration.

This system captures both kinematic and inertial effects, providing insight into how structural motion alters and is altered by the supporting ground.

In the classical Winkler foundation model, the soil is represented by a series of independent springs, and the foundation stiffness k_f may be approximated by:

$$k_f = \frac{GB}{\alpha} \quad (2)$$

Where G is the soil shear modulus, B is the foundation width, and α is an influence factor that depends on foundation shape, embedment, and Poisson's ratio (Rai, 2017). A lower shear modulus G (softer soil) reduces k_f, thereby increasing the flexibility of the system and amplifying foundation displacements.

Another well-known outcome of SSI is the lengthening of the natural period of the system compared to a fixed-base structure. This can be estimated using:

$$T_{SSI} \approx T_0 \sqrt{1+\frac{k_s}{k_f}} \quad (3)$$

where T_0 is the natural period of the fixed-base structure. A flexible foundation (k_f small) increases T_{SSI}, which can either decrease base shear demands or increase displacements depending on the response spectrum characteristics (Guerdouh & Khalfallah, 2019).

Engineering Implications

The influence of SSI on seismic performance can be beneficial or detrimental. On soft soils, SSI tends to increase displacements and modify load distributions, while on stiff soils, it can reduce accelerations by filtering high-frequency motion (Ahn, Park, Yoon, Han, & Jung, 2021). Modern seismic design standards therefore recommend evaluating SSI explicitly for tall, massive, or base-isolated structures. Advanced analyses often use finite-element or boundary-element formulations, nonlinear soil models, and experimental validation through centrifuge or shaking-table tests.

Recent studies emphasize that SSI effects are highly dependent on parameters such as soil stiffness, foundation embedment, aspect ratio, and the frequency content of ground motion (Bapir et al., 2023; Camayang et al., 2025). Neglecting SSI can lead to under- or over-estimation of seismic demands, inaccurate prediction of drift and rotation capacities, and misrepresentation of damage distribution in critical structural elements.

Case Study

The structure analyzed in this study is a regular mixed reinforced concrete building (frames braced by shear walls). It comprises six stories above ground level and one basement, with 20 cm-thick reinforced concrete shear walls providing the primary lateral resistance. The building's overall plan dimensions are 22.5 m in length, 15.44 m in width, and 29.62 m in total height.

According to the Algerian Seismic Resistant Regulation (RPA 2003), the structure is classified under Usage Group II, which corresponds to buildings intended for standard occupancy. For the purpose of seismic analysis, the building site is assumed to be located within Seismic Zone IIa, representing an area of moderate seismic hazard as defined by the code provisions.

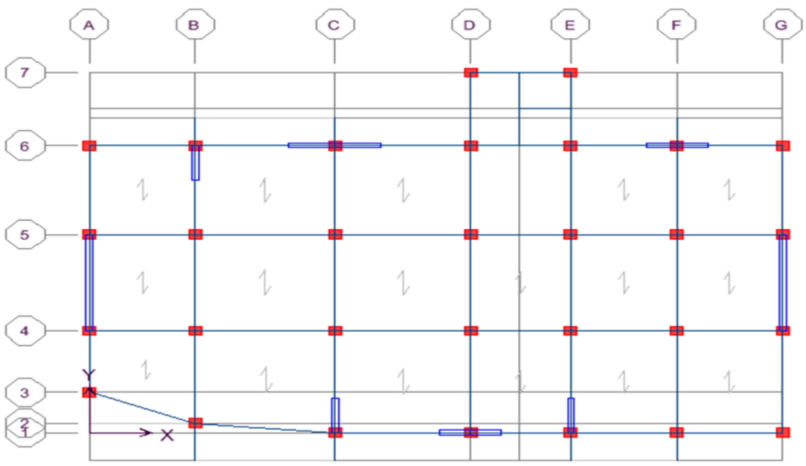

Figure 3. Plan view of the structure

The geometric characteristics of the structure are given in Table 1.

Table 1. Geometric characteristics of the structure studied.

	Description	Value (m)
Total length	L	22.85
Total width	l	15.44
Total height	H	29.62
Basement	h_b	4.44
Ground floor height	h_{GR}	4.08
Current storey height	h_{cs}	3.06

The dimensions and cross-sections of the building's structural elements (columns, beams, shear walls, slabs) are shown in Table 2. The columns, beams, shear walls and slabs (balcony) of the structure were considered to be made of reinforced concrete with linear elastic behavior. The material proprieties are summarized in Table 3. The behavior of the structural elements was considered as linear elastic. A structural Rayleigh damping ratio of 8.5% was assigned for all the elements in the concrete frame-shear wall building.

Table 2. Structural sections considered in the building

Section	Notation	Section (cm^2)	Thickness (cm)
Columns storey SB-GF-CF1	C1	45X45	/
Columns storey 2-3-4	C2	40X40	/
Columns storey 5-6	C3	35X35	/
Shear wall	SWCF	/	20
	SWGF	/	20
	SXB	/	25
Beam	PB	30X40	/
	SB	30X35	
Balcony slab	BS	/	15
Slab (hollow body)	HBS	/	20

Table 3. Material properties considered for the structural elements in the building

Parameter	Notation	Columns, beams and shear walls
Young modulus (GPa)	E	32
Shear modulus (GPa)	G	12.5
Volumic weight (kg/m^3)	ρ	2500
Poisson ratio	ν	0.2
Damping ratio	ξ	0.085

To study the effect of the interaction soil structure on the dynamic response of the structure, the seismic action is introduced using a design response spectrum. The dynamic characteristics of the structure according to RPA 2003 are shown in Table 4.

Table 4: Dynamic properties of the building

Behavior coefficient R	Acceleration coefficient zone A	Dynamic amplification factor D		Quality factor Q
3,5	0,15	Dx	1,898	1,20
		Dy	1,650	

Numerical Analysis of Dynamic Response of the Structure

This work consists of calculating the response of the structure (with and without ISS) in terms of fundamental periods for the 4 site classes defined by the Algerian seismic code (RPA 2003) (rock, firm, soft, very soft), as well as the shear force at the base of the structure and the displacement at the top of the structures.

The dynamic response of the structure under study is first evaluated by considering the assumption of perfect embedding at the base, and secondly by considering the soil-structure interaction model for the four types of response spectra associated with the different soil classes. To analyze the problem, a numerical finite element (FE) approach was employed using the structural analysis software ETABS (Computers and Structures Inc., 2019). ETABS enables the implementation of the modal response spectrum method in which individual modal responses are combined through the Complete Quadratic Combination (CQC) rule, as recommended for structures exhibiting closely spaced natural frequencies (Chopra, 2017; Wilson, 2002).

In the numerical model, columns and beams were represented using frame elements, while floor slabs were modeled as deck elements ensuring in-plane diaphragm action. The shear walls and balcony slabs were discretized with shell elements, capable of representing both in-plane (membrane) and out-of-plane (bending) actions. The frame elements were defined as two-noded, straight finite elements with six degrees of freedom (DOF) per node: three translational and three rotational. The shell elements were modeled as four-noded, flat finite elements providing a total of 20 degrees of freedom, allowing for a realistic simulation of wall and slab behavior under lateral loading (Bathe, 2014).

For the Response Spectrum Analysis (RSA), a sufficient number of modes (nine in total) were extracted to ensure that the cumulative modal mass participation reached at least 90% of the total seismic mass, as required by the Algerian Seismic Resistant Regulations (RPA 2003). The default mesh size provided by ETABS was adopted after mesh sensitivity checks showed negligible variation in modal results.

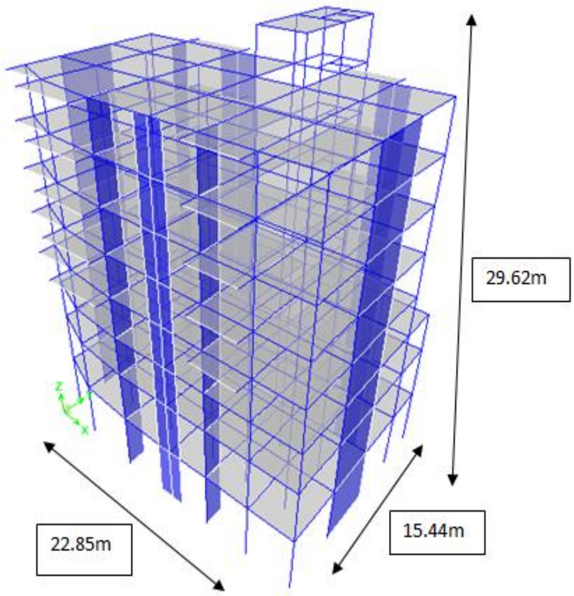

Figure 4. Numerical simulation of structure by ETABS 2019

The arrangement of shear walls was configured such that the first and second vibration modes corresponded primarily to translational motions along the X and Y axes, respectively, while the third mode represented torsional rotation about the Z-axis. The calculated eccentricities between the center of mass and the center of rigidity were ex = 0.00597 m and ey = 0.02873 m, confirming that torsional coupling effects were minimal. The characteristic values of the permanent (G) and variable (Q) loads applied to the different structural elements are summarized in the table below.

Table 5. Dead and live loads

Element	Terrace floor	Current floor	Balcony
G (KN/m^2)	7.21	5.35	5.21
Q (KN/m^2)	1	1,5	3,5

Classification of Sites According to RPA 2003

According to the RPA 2003 seismic design code, sites are classified into four categories: S1, S2, S3, and S4, based on the mechanical properties and stiffness of the underlying soils.

Table 6. Characteristics of the different categories of sites. (RPA 2003)

Site	Description	Velocity V_S (m/s)	E (MPa)	ν
S_1	Rock	≥ 800	2800	0.41
S_2	Firm	≥ 400-<800	830	0.44
S_3	Soft	≥ 200--<400	300	0.40
S_4	Very soft	≥ 100--<200	127	0.37

Modelling of the Structure without Considering Soil–Structure Interaction (SSI)

In the case of modelling without soil–structure interaction (SSI), a perfectly fixed base is assumed at the foundation level. This assumption corresponds to the traditional modelling approach generally adopted for standard building structures. The structural materials are assumed to exhibit a linear elastic behaviour, allowing for a direct assessment of the global dynamic response. The seismic response of the structure is evaluated using the four design response spectra corresponding to the different site categories as defined in the seismic design code (RPA 2003).

Modelling of the Structure Considering Soil–Structure Interaction (SSI)

In this stage of the study, the same structural model previously defined is adopted, with the inclusion of the effects of soil–structure interaction (SSI). The supporting soil is considered to be homogeneous and to exhibit a linear elastic behaviour throughout the analysis. This assumption allows for a simplified yet sufficiently accurate representation of the dynamic interaction between the structure and its foundation, enabling a direct evaluation of the influence of soil flexibility on the global response of the system.

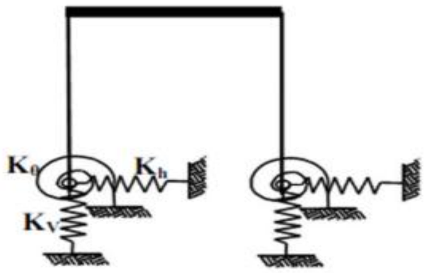

Figure 5. Simplified model of soil-structure interaction

The soil spring model represents the elastic response of the soil to both the translational and rotational displacements of the foundation. The simplest and most widely used approach to account for soil behaviour consists in modelling the soil as a discrete system of springs uniformly distributed beneath the foundation slab. These springs connect the nodes of the foundation to a rigid base, on which the prescribed seismic or dynamic movements are applied. This modelling technique provides a practical means of simulating the deformability of the soil while maintaining computational efficiency within the structural analysis.

Calculation of Stiffness Coefficients

Several formulations have been proposed for calculating the stiffness of soil springs. Among the most widely used are those developed by Newmark and Rosenblueth (1971), Deleuze (1988), and the simplified method proposed by Veletsos, as reported by Davidovici (1999) and Zaceck (1996).

Table 7. Stiffnesses of soil springs (Newmark-Rosenblueth,1971)

Movement	Rectangular rigid foundation
Horizontal	$K_h = 2(1+\nu)G\beta_x\sqrt{BL}$
Vertical	$K_v = \frac{G}{1-\nu}\beta_z\sqrt{BL}$
Rocking	$K_\phi = \frac{G}{1-\nu}\beta_\phi BL^2$

Where:
L is the dimension of the foundation parallel to the direction of the seismic action.
B is the dimension of the foundation perpendicular to the direction of the seismic action.
υ is the Poisson's ratio

G is the shear modulus and it is given by the relationship: $G = \frac{E}{2(1+\nu)}$ (4)

In the present study, the stiffness values of the soil springs are determined using the relationships provided in Table 7, which take into account the mechanical characteristics of the sites described in Table 6. The dimensionless coefficients β_x, βz, and β_φ, also presented in Table 7, are obtained from specific design charts that depend on both the foundation aspect ratio (b/a) and the direction of the considered seismic excitation (Newmark & Rosenblueth, 1971).

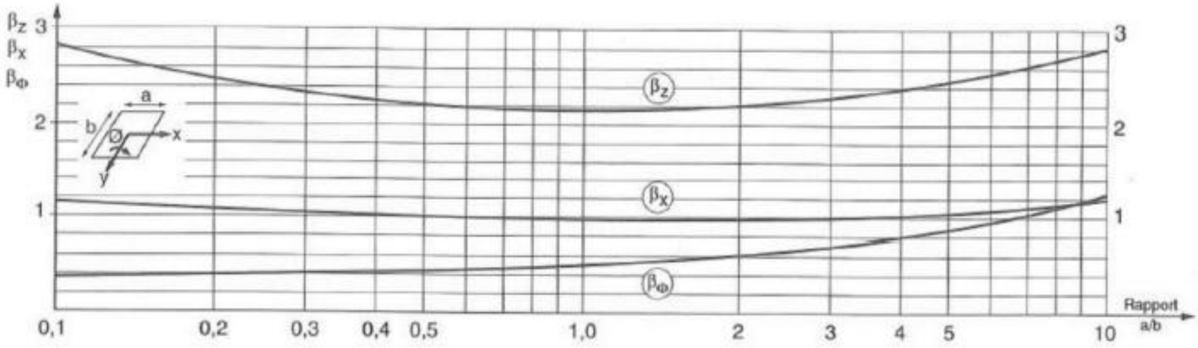

Figure 6. Chart of newmark-rosenblueth coefficients (Davidovici,1999).

The foundation of the studied structure consists of a rectangular raft footing with a length of 22.85 m and a width of 15.44 m (L/B = 1.48). The corresponding foundation coefficients are β_x = 0.98, βz = 2.20, and βφ = 0.48. The calculated soil stiffness values corresponding to the various site categories are summarized in Table 8.

Table 8. Values of soil stiffness.

Site	K_h (KN/m)	K_v (KN/m)	Kφ (KN.m/rd)
Site1	$5{,}19.10^4$	$2{,}9.10^7$	$2{,}72.10^{15}$
Site2	$5{,}30.10^4$	$8{,}27.10^6$	$7{,}74.10^{14}$
Site3	$5{,}15.10^4$	$3{,}16.10^6$	$2{,}96.10^{14}$
Site4	$5{,}04.10^4$	$1{,}39.10^6$	$1{,}30.10^{14}$

Results and Discussion

The numerical simulation results for both models, with and without soil–structure interaction, are presented discussed in the following section.

Fundamental Period T

The results illustrated in Figure 7 show the variation of the fundamental period for the four site categories (S1 to S4), comparing the structural models with and without soil–structure interaction (SSI). The fundamental period of the structure remains constant across all site classes when soil–structure interaction (SSI) is neglected. This behavior results from the assumption of a perfectly rigid base, where the dynamic characteristics of the system depend solely on the stiffness and mass distribution of the superstructure.

When SSI is considered, however, a clear variation of the fundamental period is observed depending on the soil type. The results indicate a progressive increase in the fundamental period as the soil becomes more deformable. This phenomenon occurs because the inclusion of the soil medium introduces additional flexibility to the system, effectively reducing its overall stiffness. The increase in period reaches approximately 16% for site S4 (very soft soil) compared with the fixed-base model.

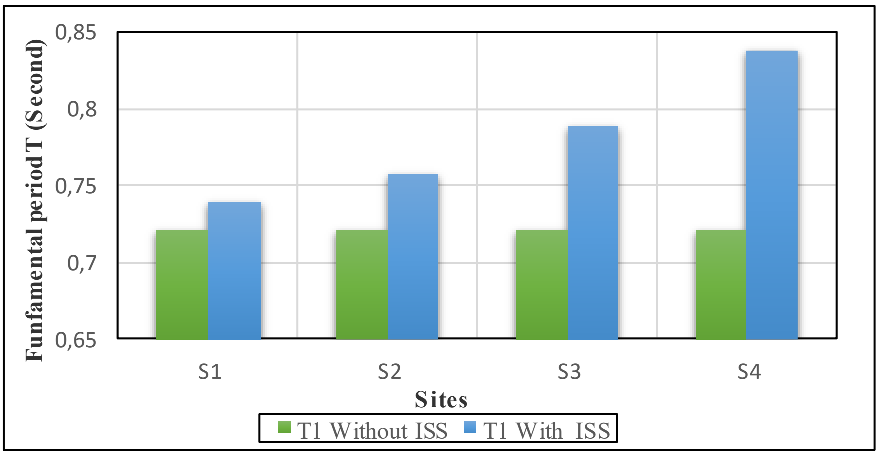

Figure 7. Variation in the fundamental period depending on the site (with and without ISS).

A quantitative comparison shows that the fundamental period increases by about 2% for site S2, 5% for site S3, and up to 16% for site S4 when SSI is incorporated. This trend confirms that the influence of SSI becomes increasingly significant for soft and very soft soils, where the soil compliance has a dominant effect on the overall dynamic response. For the softest site (S4), the computed fundamental period reaches 0.837 s, whereas the reference value defined by the RPA code (0.825 s) is slightly lower. This discrepancy implies that neglecting SSI may lead to an underestimation of the structural flexibility, and consequently to a potential under-design of the structure in seismic regions. Therefore, accounting for SSI is crucial in seismic analysis, especially for flexible or semi-rigid structures founded on deformable soils. These findings are consistent with the results reported by Veletsos (1975), Wolf (1985), and Gazetas (1991), who demonstrated that soil–structure interaction generally lengthens the natural period of vibration due to the added compliance of the foundation–soil system.

Base Shear Force

Figure 8 presents the variation of the base shear force (V) for the structure, both with and without soil–structure interaction (SSI), across the four site classes (S1–S4).

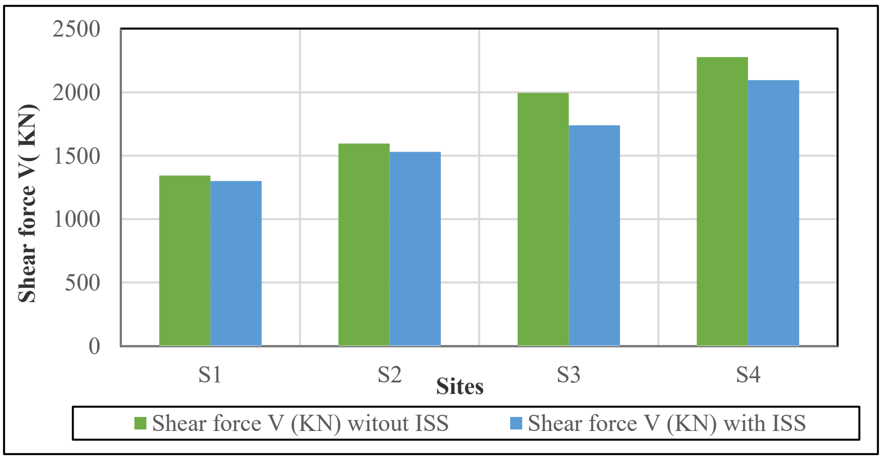

Figure 8. Variation of base shear force depending on the site (with and without ISS).

It can be clearly observed that the base shear decreases when SSI is considered. This reduction becomes more pronounced as the soil flexibility increases, with the most significant difference occurring for soft and very soft soils. The results show that the base shear obtained without SSI is systematically higher than that obtained with SSI for all site conditions.

A detailed comparison between the two cases reveals that the inclusion of SSI leads to a reduction in base shear of approximately 3% for site S1, 4% for site S2, 14% for site S3, and 8% for site S4. This clearly indicates that the influence of SSI becomes increasingly significant for softer soils, where the deformability of the ground plays a dominant role in the seismic response.

This trend can be attributed to the increase in the fundamental period of the system due to soil flexibility. When SSI is taken into account, the structure–foundation system behaves more flexibly, resulting in a longer vibration period and consequently lower spectral accelerations. This leads to a reduction in the inertial forces transmitted to the base, and thus a decrease in the base shear. These findings are consistent with the results reported by Veletsos and Meek (1974), Wolf (1985), and Gazetas (1991), who demonstrated that the inclusion of SSI generally increases the fundamental period while decreasing the base shear, particularly for structures resting on soft or very soft soils.

Absolute and Relavie Displacements

The variation of the maximum absolute and relative displacements, with and without considering soil–structure interaction (SSI), is illustrated in Figure 9 and 10.

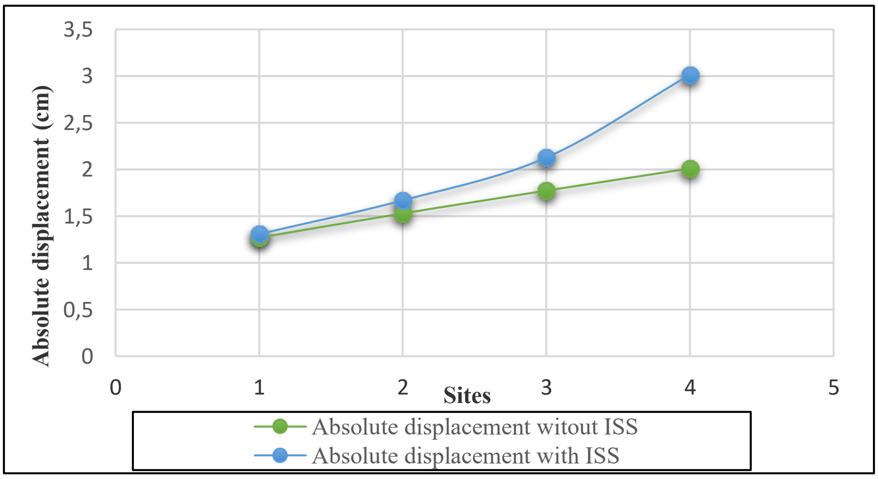

Figure 9. Variation of absolute displacement depending on the site (with and without ISS).

An overall increase is observed across all sites when the influence of soil–structure interaction (ISS) is taken into account. The comparison between the cases without and with ISS shows that the absolute displacement increases by approximately 3% for Site 1, 9% for Site 2, 20% for Site 3, and 50% for Site 4. This progressive increase demonstrates that the flexibility of the supporting soil plays a significant role in amplifying the lateral displacements of the structure. The effect becomes particularly pronounced for soft soils, where the interaction between the foundation and the deformable medium reduces the overall stiffness of the soil–structure system.

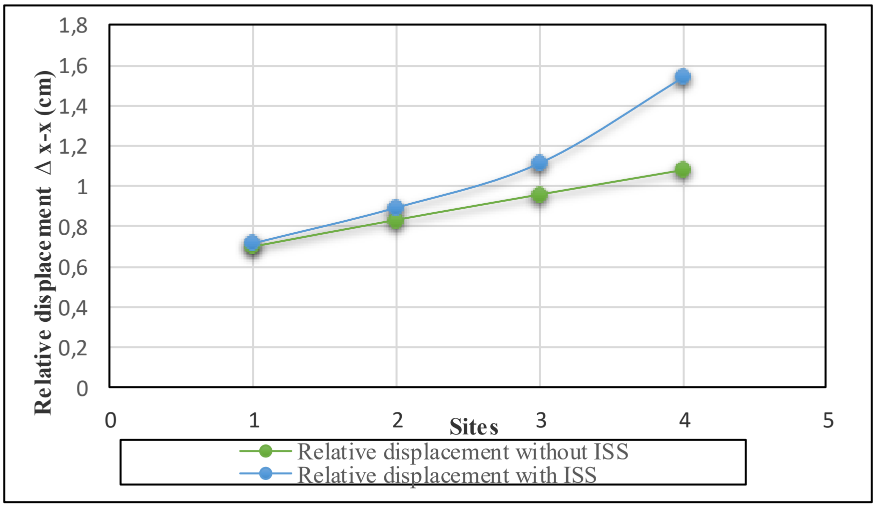

Figure 10. Variation of relative displacement depending on the site (with and without ISS)

Similarly, for the maximum relative displacement, an increase is observed across all sites in both cases, with and without SSI. The results indicate that the more deformable the soil, the greater the relative displacement. This behaviour is mainly attributed to the reduction in the overall stiffness of the soil–structure system when SSI is included. Nevertheless, the maximum relative displacement values remain below the permissible limit (h/100), ensuring that inter-storey drifts are within acceptable serviceability limits.

These results are consistent with previous research findings. Mylonakis and Gazetas (2000) and Wolf (1985) demonstrated that considering SSI leads to higher lateral displacements due to the lengthening of the fundamental period and the reduction of system stiffness. Gazetas (1991) and Kwon and Elnashai (2006) further highlighted that this effect becomes particularly important for flexible and tall structures founded on soft soils. Similarly, Abdel Raheem et al. (2013) confirmed that neglecting SSI may result in underestimation of the displacement demand, especially for structures resting on deformable soil profiles.

Conclusion

From the results obtained for the fundamental period, base shear force, and maximum and relative displacements, it can be concluded that soil–structure interaction (SSI) has a significant influence on the dynamic response of the studied structure. The inclusion of SSI leads to an increase in the fundamental period, indicating a reduction in the overall stiffness of the soil–structure system. Consequently, the structure exhibits more flexible behaviour when resting on deformable soils. This change in stiffness also affects the base shear force, which decreases as soil flexibility increases. The reduction in base shear is mainly due to the lengthening of the natural period and the redistribution of inertial forces between the structure and the supporting soil. Such a decrease, however, should not be interpreted as a reduction in seismic demand, as it is accompanied by larger displacements.

Indeed, both the maximum absolute and relative displacements show a clear amplification when SSI is considered. The more flexible the soil, the greater the increase in lateral displacements, with a particularly marked effect for Sites 3 and 4, corresponding to soft soil conditions. Despite this amplification, the displacements remain within the permissible limits (h/100), ensuring acceptable structural performance under the considered seismic loading.

Overall, these findings highlight the necessity of accounting for SSI effects, especially for structures built on soft or medium soils. Neglecting SSI may lead to an overestimation of stiffness and base shear, and an underestimation of displacements, which could compromise both the safety and serviceability of the structure. Therefore, the inclusion of SSI is strongly recommended in seismic analysis and design, particularly for semi-rigid and flexible structures located in zones II, III, and for soft soil sites.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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