The Eurasia Proceedings of Science, Technology,
Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2023

Volume 26, Pages 49-59

IConTES 2023: International Conference on Technology, Engineering and Science

Evaluation of the Seismic Response of Reinforced Concrete (RC) Buildings Considering Soil-Structure-Interaction Effects

Adnane Brahma
University of Science and Technology Houari Boumediene (USTHB)

Mohamed Beneldjouzi
University of Science and Technology Houari Boumediene (USTHB)

Mohamed Hadid
National High School of Public Works (ENSTP)

Mustapha Remki
Earthquake Engineering Applied Research Center (CGS)

Abstract: The dynamic response of the structure is influenced by soil-structure interaction (SSI), and is distinct from the fixed-base one. When stiff structures are supported by soft to very soft soil, SSI has a substantial effect. This work intends to investigate the effects of SSI using various estimation techniques in order to quantify the foundation damping effect on the response of reinforced concrete (RC) buildings. Generalized and completely viscous damping formulas were utilized to estimate the damping of the soil-foundation system. The investigated structures are 4, 8, and 12-story RC buildings built on very soft soil in a high seismic zone. In comparison to the fixed base condition, the study demonstrated an increase in the natural period, damping of the system, and a decrease in base shear. The study's response parameters are compared to those obtained in accordance with ASCE7-16 code provisions.

Keywords: Foundation damping, SSI, RC building, Base shear, ASCE7-16

Introduction

Seismic analysis of civil structures is often made with the assumption of a fixed base corresponding to rigid-rock. This assumption becomes invalid in the case of flexible base, due to the added flexibility provided to the SFS system (Avilés & Pérez Rocha, 2011). When subjected to seismic motion, the structural response and the free-field ground displacement are not independent of each other. The seismic waves excite the structure, which in turn, modifies the input ground motion. This difference in motion is due to interaction between the foundation, the geological backgrounds underlying and surrounding the foundation, and the superstructure. Dynamic response analysis of foundations supporting structures subjected to seismic excitations is, hence, a key step in structural seismic design and plays a substantial role in the analysis of soil-foundation-structure (SFS) system.

The effect of SSI is more significant in short-period low-rise buildings in contrast to long-period high-rise structures. Buildings considered in this study are low-to-mid-rise resting on soft soil, and are expected to exhibit SSI effects that would alter the response of the buildings considered.

This study evaluates the seismic response of RC multi-story buildings accounting for soil-foundation-structure interaction (SFSI) effects and examines their direct impact on the key parameters of seismic design.

Two approaches were used to calculate the damping foundation. The first one is that provided by the NIST-GCR (2012) provisions and the second is proposed by Givens et al. (2016). The first solution is entirely expressed in terms of real-valued variables, whereas the second involves complex variables and results in complex-valued expressions that are employed with the modular foundation damping solutions. The buildings selected are designed first based on the Algerian Seismic Rules (RPA99, 2003) for their fixed base condition and then designed again according to the substructure approach, which consists of replacing soil deposits with an appropriate spring-dashpot system to model the soil flexibility. Findings show that SFSI is beneficial for the structure and results in a reduction of global base shear force due to a lengthening of the fundamental vibrating period, which leads to a reduced spectral acceleration. Comparison with ASCE7-16 code provisions allowed confirmation of the results of the study.

Soil-Structure Model Considered

SSI effects produce kinematic interaction effects related to the inability of foundation to follow the ground motion due to the greater foundation's stiffness in comparison with soil's stiffness, and inertial interaction effects resulting in inertial forces developed within the structure due to the existence of structural and foundation masses.

Most technics for analyzing SSI interaction effects are mainly based on two methods: (1) the direct method, in which the soil and the structure are included in the same model and are analyzed as a complete and unique system; and (2) the substructure method, which involves dividing the SFS system into separate parts that are combined to formulate the complete problem solution.

According to pioneering works in the field (Stewart & Fenves, 1998), figure 1.b illustrates the retained SFS rheological model, where the superstructure is represented by a single degree of freedom (1-DOF) system with a height h, mass m, stiffness k and viscous damping factor c. This system is connected to a rectangular foundation of dimensions L and B ($L \geq B$). Following the substructure approach, the soil deposits are replaced by a discrete spring-dashpot system described by impedance functions, which reflect the stiffness and the energy dissipation effect mobilized during a seismic excitation given the soil flexibility.

The base of the structure is allowed to move with respect to the free-field motion with u_0 value and to rotate through an angle θ (Figure 1.b). After replacing the soil deposits by impedance functions, the system is converted into an equivalent SFS system, where the stiffness K_u and K_θ and damping factors c_u and c_θ correspond, respectively, to the translation according to x axis, and rocking about y axis modes (coupling terms, mass and mass moment of inertia of the foundation are neglected).

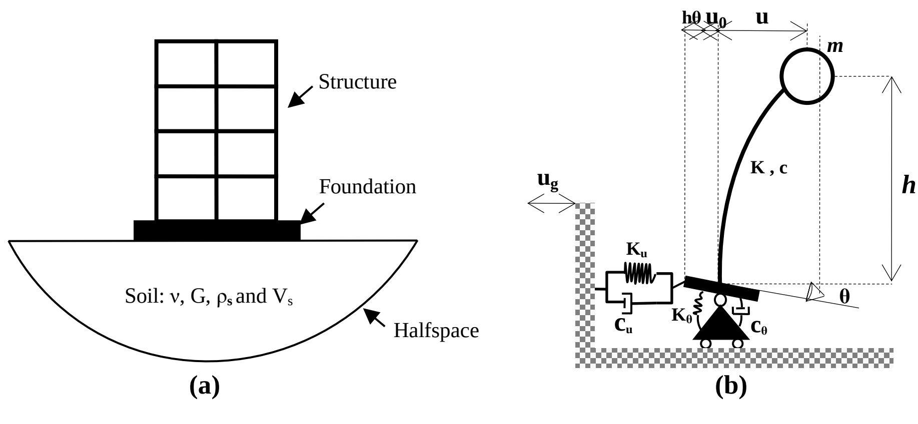


Figure 1. SFS model: (a) Simplified model and (b) Rheological model.

Several authors (Stewart et al., 1999 among others), have shown that the system of Figure 1.b may adequately represent approximate model of a structure with several DOFs having several vibration modes, but whose global response is dominated by the fundamental mode. In such a model, h and m represent, respectively, the effective height and mass associated with the first mode of vibration. Previous studies (Jennings & Bielak, 1973; Stewart

& Fenves, 1998) have shown that the influence of higher modes on the effect of SFSI is negligible. The model of figure 1.b is therefore well suited to the dynamic SFSI analysis of multi-story RC buildings. In this model, the total displacement, u_t of mass m is given by:

$$u_t = u_g + u_0 + h\theta + u \qquad (01)$$

Where, u_t, u_g and u_0 are, respectively, the total displacement, the displacement of the foundation and the displacement of the ground; u represents the amplitude of the relative displacement of mass m with respect to a moving benchmark attached to the rigid base, and θ, the rotation of the foundation relative to an axis perpendicular to the study plane

Effects of the Foundation Flexibility

In a building resting at a shallow depth on soft soil deposits, the flexible base effect is represented using dynamic frequency-dependent impedances. The latter define stiffness and energy dissipation of the system caused by radiation of waves and by hysteretic action of the ground for the various degrees of freedom, which are limited, in the case of the present study, to the modes of translation according to the x-axis and the rocking around the y-axis. The first consequence of the SFSI effects is the vibration period lengthening of the system initially with fixed base, due to the flexibility introduced by the underlying soil deposits.

If T represents the natural period of the structure in its fixed-base condition, and $\tilde{T}$ represents the period of the modified structure which approximates the flexibly supported system, it can be shown (Veletsos & Meek, 1974) that:

$$\frac{\tilde{T}}{T} = \sqrt{1 + \frac{k}{k_x} + \frac{kh^2}{k_{yy}}} \qquad (02)$$

Equation (2) may be applied to fundamental mode dominated multi-degree-of-freedom structures considering the first mode effective parameters (modal mass, modal stiffness and effective building height). k_x, represents the lateral translational stiffness of the foundation; and k_{yy}, denotes the rocking stiffness of the foundation; k, is the stiffness of the superstructure corresponding to the first mode of vibration along the x axis; m and h, correspond, respectively, to the modal mass and effective height of the structure. $\tilde{T}$ /T is a ratio greater than 1, which denotes the vibration period lengthening of the system initially on a fixed base.

Impedance Functions and Damping of the Soil

Impedance Functions

Impedance functions are complex expressions representing the stiffness and the frequency-dependent radiative and material damping characteristics in an SFSI problem, analyzed through the substructure approach. Their classic form is given by:

$$K_j^{d} = K_j^{s}(k_j + i\omega c_j) \qquad (03)$$

$$K_j^{s} = k_j^{0}\alpha_j\eta_j \qquad (04)$$

Where K_j^{d} is the complex-valued dynamic impedance function; j indicates the mode of displacement (translation or rotation); k_j^0, represents the static stiffness of the foundation at zero-frequency for mode j; k_j and c_j denote, respectively, the stiffness and frequency-dependent damping coefficient for mode j and ω, the circular frequency (rad/s). Also, the static stiffness of the foundation is affected by correction coefficients (α_j and η_j), to account, respectively, for the dynamic and embedment effects of the foundation when it is the case.

The determination of impedance functions is one of the most critical steps involved in substructure approach. For practical applications, they are generally treated as independent of frequency. The most common values of their terms are those corresponding to zero-frequency (static components). Several authors have proposed solutions for impedance functions for different modes of displacement (Veletsos & Wei, 1971;Pais & Kausel, 1988). The terms of the impedance functions used in this study are those of Pais and Kausel (1988) (Table 1).

Table 1. Equations for shallow foundation stiffness and damping of Pais and Kausel (1988)

Degree of freedom	Static stiffness	Dynamic stiffnesses
Translation along x-axis	$K_{Hx}^{s} = \frac{GB}{2-\nu}\left[6.8\left(\frac{L}{B}\right)^{0.65} + 2.4\right]$	$\overline{K}_{Hx}^{d} = K_{Hx}^{s}(k + ia_0c)$ $k = 1.0$; $c = \frac{4(\frac{L}{B})}{K_{Hx}^{s}/GB}$
Rocking about y-axis	$K_{Ry}^{s} = \frac{GB^3}{1-\nu}\left[3.73\left(\frac{L}{B}\right)^{2.4} + 0.27\right]$	$\overline{K}_{Ry}^{d} = K_{Ry}^{s}(k + ia_0c)$ $k = 1.0 - \frac{0.55a_0^2}{b+a_0^2}$; $c = \frac{\left(\frac{4\alpha}{3}\right)(\frac{L}{B})^3}{K_{Ry}^{s}/GB^3}\frac{a_0^2}{f+a_0^2}$ $b = 0.6 + \frac{1.4}{(\frac{L}{B})^3}$ $f = \frac{1.8}{1.0 + 1.75(\frac{L}{B} - 1)}$

In table 1, $a_0 = \frac{\omega B}{V_s}$ is the dimensionless frequency; $\alpha = \sqrt{2(1-\nu)/(1-2\nu)} \leq 2.5$ and $G = \rho_s V_s^2$, is the elastic shear modulus. The damping ratios are defined as:

$$\beta_j = \frac{a_0 c_j}{2k_j} \tag{04}$$

Damping

The total damping, β_{SSI}, associated with the soil-foundation interaction is composed of the contribution of two damping types: (1) viscous damping related to the superstructure, and (2) the foundation damping accounting for the hysteretic (material) damping along with radiative (geometric) damping.

Hysteretic damping relates to the physical nonlinearities of the soil and characterizes the energy dissipation by friction between its particles, whereas the radiation damping reveals the seismic energy reflected into the ground in the form of waves, when the incident seismic field meets the elements of the foundation. Indeed, the foundation elements behave as a rigid body with a stiffness much greater than that of soil deposits. Foundation damping is a direct contributor to the flexible-base system damping, β_{ssi}, the following expression for the calculation of the SFS system total damping as follows(Wolf, 1985;Veletsos & Meek, 1974):

$$\beta_{ssi} = \beta_f + \frac{\beta_{st}}{\left(\frac{\tilde{T}}{T}\right)_{eff}^{2}} \tag{05}$$

Where β_f, is the total foundation damping, and β_{st}, the viscous damping ratio related to the superstructure. In this study we used two expressions for foundation damping. The first was developed by the authors for (NIST GCR, 2012) can write as follows:

$$\beta_f = \left[\frac{\left(\frac{\tilde{T}}{T}\right)^2 - 1}{\left(\frac{\tilde{T}}{T}\right)^2}\right]\beta_s + \left(\frac{1}{\left(\tilde{T}/T_x\right)^2}\right)\beta_x + \left(\frac{1}{\left(\tilde{T}/T_{yy}\right)^2}\right)\beta_{yy} \tag{06}$$

The second expression is proposed by (Givens et al., 2016)as follows:

$$\beta_f = \frac{1}{\left(\tilde{T}/|\overline{T_x}|\right)^2}(\beta_x + \beta_s) + \frac{1}{\left(\tilde{T}/|\overline{T_{yy}}|\right)^2}(\beta_{yy} + \beta_s) \quad (07)$$

Where β_s, Is the soil hysteretic damping ratio, β_x and β_{yy} are damping ratios related to radiation damping from translational and rotational modes (described further in section above). T_x, T_{yy}, $|\overline{T_x}|$ and $|\overline{T_{yy}}|$ are fictitious vibration periods, complex and real-valued respectively calculated as if the only source of the vibration was foundation translation or rotation, as follows:

$$\begin{cases} |\overline{T_x}| = 2\pi\sqrt{\dfrac{m}{|\overline{k_x}|}} \\ |\overline{T_{yy}}| = 2\pi\sqrt{\dfrac{mh^2}{|\overline{k_{yy}}|}} \end{cases} ; \qquad \begin{cases} T_x = 2\pi\sqrt{\dfrac{m}{k_{x,surf}}} \\ T_x = 2\pi\sqrt{\dfrac{mh^2}{k_{x,surf}}} \end{cases}$$

The complex-valued impedance functions as follows:

$$\overline{k_j} = k_j[1 + 2i(\beta_j + \beta_s)] \quad (12)$$

Where: k_j and c_j are dimensionless parameters functions of a_0, ν = Poisson's ratio; j indicates the mode of displacement (translation or rotation) (Table 1).

Design Provisions

The concepts described in the preceding sections have provided the basis of the SSI design. For buildings analyzed without regard for SSI, the total lateral force or base shear, V, is expressed according to the Algerian Seismic Rules (RPA99, 2003) in the case of the equivalent static method is expressed as:

$$V = C_s W \quad (13)$$

in which, W, the total weight of the building. including the dead weight and the effective portion of the design live load. and ,C_s, the lateral force coefficient which represents the ratio of the effective spectral acceleration for the system, is defined by the following ratio (RPA99, 2003) :

$$C_s = \frac{ADQ}{R} \quad (14)$$

Where, *A* is the zone acceleration coefficient, *D* is the dynamic amplification factor, *Q* is the quality factor and *R*, is the behavior factor. In the present study, parameters needed in the C_s formula were calculated following the section 4.2.3 of the RPA99: *A* = 0.25; *D* = 2.2 (fixed base); *Q* = 1.2 and *R* = 3.5; *D* has been assessed based on appropriate formula of structural period, provided by the RPA99 provisions.

The variation of C_s with T is represented by a function which is initially constant and then decreases with increasing T. As a result, consideration of soil-structure interaction in this case will reduce the design values of the lateral forces, shears and overturning moments below the levels applicable to a rigid-base condition. In this regard, (ASCE7-16, 2007) proposes expression which aims to consider reduction in the global base shear force, which has been used in accordance to RPA99 provisions as follows:

$$\tilde{V} = V - \Delta V \geq \alpha V \quad (15)$$

$$\alpha = 0.5 + \frac{R}{15} \quad for \quad 3 \leq R \leq 6 \quad (16)$$

Where $\tilde{V}$, is the reduced base shear force, V, is the base shear force in the fixed base condition and ΔV, the base shear force reduction:

$$\Delta V = \left[C_s - \tilde{C}_s \left(\frac{\beta_{st}}{\beta_{ssi}}\right)^{0.4}\right] \bar{W} \tag{15}$$

Where C_s and $\tilde{C}_s$, the lateral force coefficients corresponding to the fundamental natural periods of the fixed-base and the elastically supported systems, respectively; β_{ssi} the percentage of critical damping for the structure-foundation-soil system; and $\bar{W}$ is the effective weight of the structure. The base shear force of the structure considering SFSI effects in the case of the response spectrum method is given by the following expression:

$$\tilde{V}_{mod} = S_a(\tilde{T}) M^* \tag{16}$$

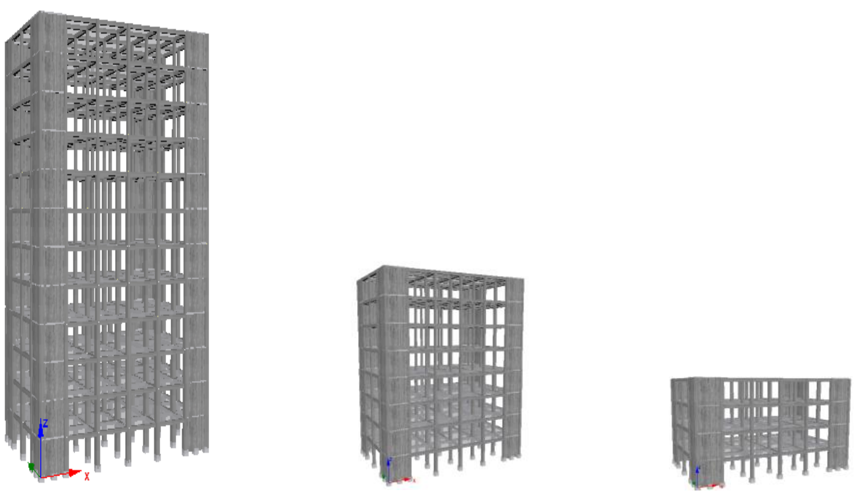
In which, M^* is the fundamental mode mass and S_a, the spectral acceleration corresponding to the flexible base period $\tilde{T}$.

Soil and Superstructure Modeling

The structures studied are multi-story reinforced concrete structures with 4, 8 and 12 storey, as a total height H= 12.8, 25.6 and 38.4 m respectifly. located in a zone of high seismicity (zone III, according to RPA99 version 2003). The buildings has mixed bracing (moment frames-shear walls) and is based on a RC mat foundation. The floors are RC two ways slab, and the wall infill of the hollow bricks. Ground and upper stories are of the same height h=3.2 m. Building structural elements are given in Table 2.

Table 2. Dimensions in Cm of building's structural element

Element		R+3	R+7		R+11		
		1-4	***1-4***	***4-8***	***1-4***	***4-8***	***8-12***
	C1 (a×b)	40×40		40×40			40×40
Column	C2 (a×b)		50×50			50×50	
	C3 (a×b)				60×60		
Beam	b (b×h)	30×40	30×40		30×40		
Slab	D (e)	20	20		20		
Wall	W (aw)	20	20		20		
E (MPA)	23500						
ν	0.3						
ρ (t/m3)	2.5						



R+11 **R+7** **R+3**

(a)

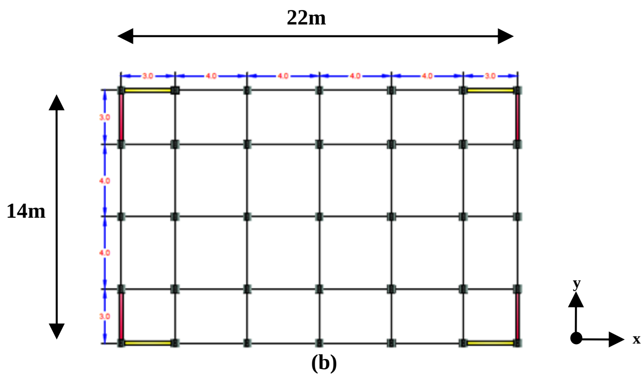


Figure 2. (a) 3D FE models of the studied buildings made with SiesmoStruct ver 2020. (b) Plan view

Table 3. Results of the first mode (fundamental mode)

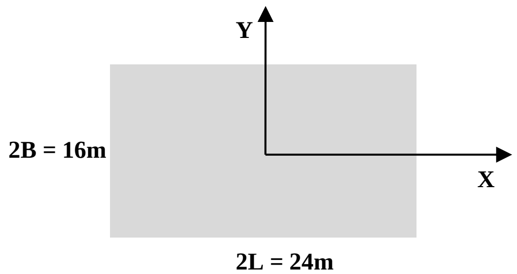
Buildings	T_i (s)	M^* (ton)	H^* (m)
R+3	0.3	1671.98	8.96
R+7	0.83	3158.16	17.92
R+11	1.38	4944.38	26.88

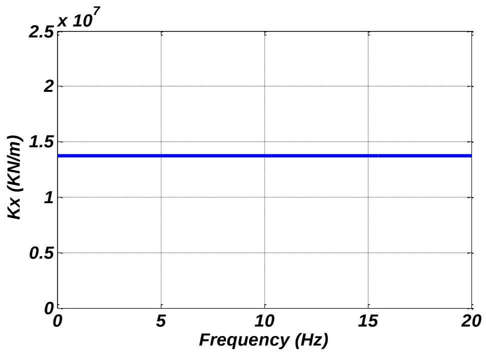
The soil is classified into the S4 category (according to (RPA99, 2003) ver 2003) and is assumed to be homogeneous with linear elastic behavior. It is characterized by its weight density ρs = 17 KN/m^3, its elastic shear modulus G = 244800 KN/m^2, its Poisson's ratio, ν = 0.4 and its hysteretic damping ratio, βs = 7%. The shear wave velocity within the soil deposits is V_S = 120 m/s (very soft site category).

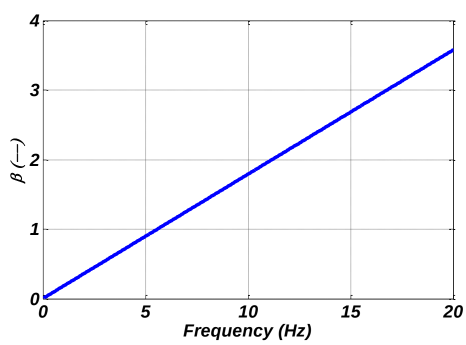
Results and Discussion

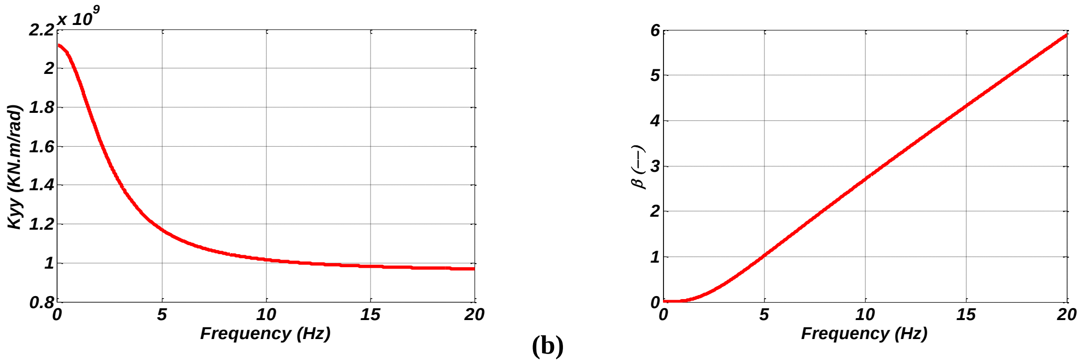
In this section, parameters needed for the ISFS analysis are calculated. Also shown in Figure 3b are stiffness and damping predictions using Pais and Kausel (1988) half space equations adapted for elastic and homogenous soil profiles following recommendations in (NIST GCR, 2012). Using the impedance ordinates in Figure 3b, we compute foundation damping using (Eq,16), for excitation in the x-direction. Table 4 clearly shows that the Givens approach produces higher foundation damping than the approach mentioned in NIST guidelines, especially for low rise (R+3) (high frequency) structures.

(a)







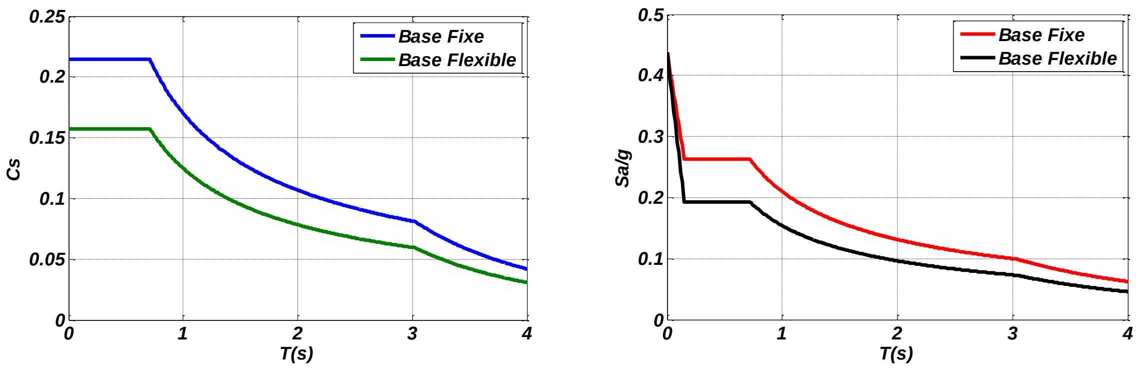


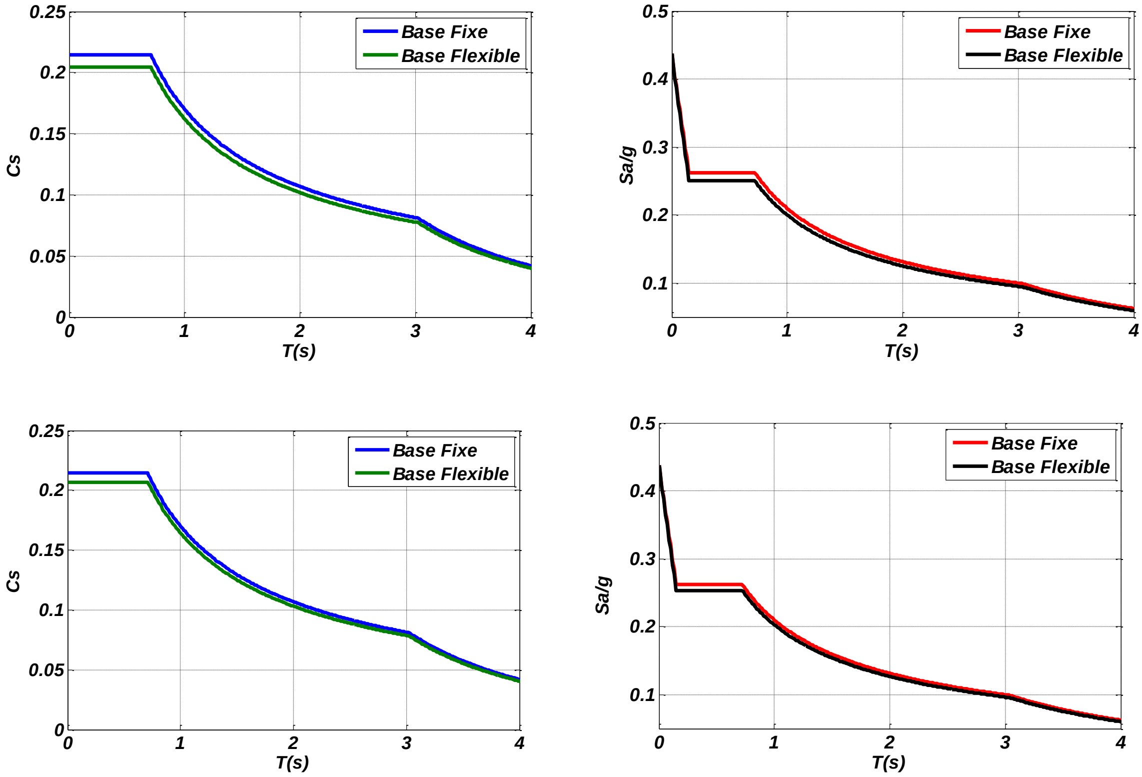
(b)

Figure 3. (a) plan view of assumed foundation geometry; (b) frequency-dependent foundation stiffness's for translation (k_x), rotation (k_{yy}), and associated radiation damping terms (β_x and β_{yy}) for y-component excitation. Foundation stiffness and damping results are shown from closed form expressions for a soil half space adapted to the present conditions following guidelines in NIST (2012).

Table 4. Parameters used in ISFS analysis

Symbole	R+3 Nist-GCR2012	Givens-2016	R+7 Nist-GCR2012	Givens-2016	R+11 Nist-GCR2012	Givens-2016
$\boldsymbol{K_i}$ (KN/m)	732669.067		180799.503		102393.634	
$\boldsymbol{K_x}\times10^7$ (KN/m)	1.377	-	1.377	-	1.377	-
$\boldsymbol{K_{yy}}\times10^9$ (KN.m/rad)	2.118	-	2.118	-	2.118	-
$\lvert\bar{\boldsymbol{k}}_x\rvert\times10^7$ (KN/m)	-	2.292	-	1.585	-	1.482
$\lvert\bar{\boldsymbol{k}}_{yy}\rvert\times10^9$ $(KN.m/rad)$	-	3.673	-	4.585	-	4.829
$\boldsymbol{\alpha_x}$	1.0		1.0		1.0	
$\boldsymbol{\alpha_{yy}}$	0.64		0.89		0.95	
$\tilde{\boldsymbol{T}}$ (s)	0.312		0.847		1.41	
$\tilde{\boldsymbol{T}}/\boldsymbol{T}$	1.04		1.02		1.02	
a_0	1.395		0.504		0.303	
$\boldsymbol{\beta_x}$	0.59		0.21		0.13	
$\boldsymbol{\beta_{yy}}$	0.48		0.039		0.009	
$\boldsymbol{T_x}$ *(sec)*	0.069	-	0.15	-	0.26	-
$\boldsymbol{T_{yy}}$ *(sec)*	0.062	-	0.146	-	0.264	-
$\lvert\bar{\boldsymbol{T}}_x\rvert$*(sec)*	-	0.0536	-	0.0886	-	0.1146
$\lvert\bar{\boldsymbol{T}}_{yy}\rvert$ *(sec)*	-	0.0499	-	0.1374	-	0.2579
$\boldsymbol{\beta_{rd}}$	0.049	-	0.004	-	0.0012	-
$\boldsymbol{\beta_f}$	0.059	0.034	0.009	0.006	0.007	0.004
$\boldsymbol{\beta_{ssi}}$ (%)	11%	8%	5.7%	5.4%	5.5%	5.2%





(a) (b)

Figure 4. (a) Reduction of the seismic response coefficient in the case of fixed and flexible base conditions, (b) Design response spectrums corresponding to the S4 site for fixed and flexible base conditions according to RPA99 provisions.

It is clear, from obtained results that consideration of flexible support is beneficial for the seismic structural response and results in a reduction in the design base shear force. This reduction is relatively important in the case of the equivalent static method, which could be explained by the very soft nature of the S4 site having resulted in a high damping effect.

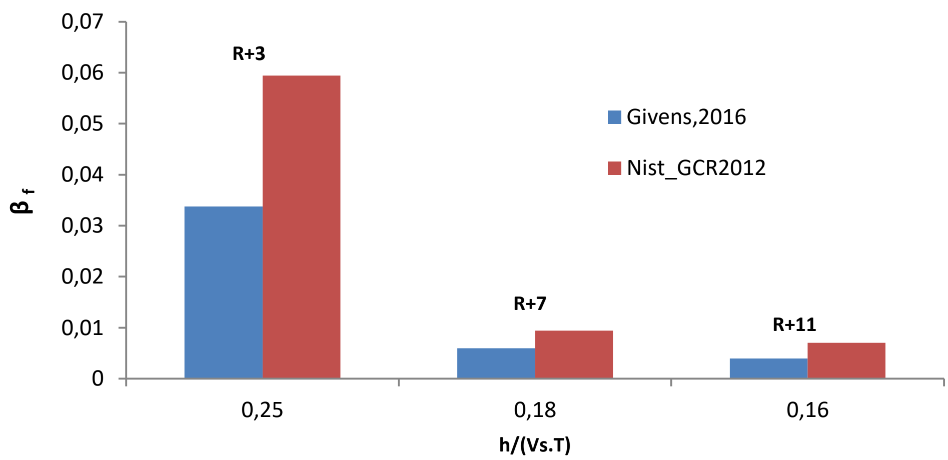


Figure 5. Comparison of foundation damping solutions based on NIST provisions (2012) Eq (6), and Givens (2016) Eq (7).

Figure 5 clearly shows that the damping calculated with the approach using generalized damping formulas (which takes into account the hysterical and viscous components (Givens' approach)) is lower than that calculated with the approaches adopted in NIST-GCR2012, particularly for low-rise building (R+3).

Table 5. Fixed and flexible base shear force reduction in equivalent static method retained by the RPA99 provisions.

	Equivalent static force procedure					
	NIST-2012			Givens-2016		
	R+3	R+7	R+11	R+3	R+7	R+11
$V\ (KN)$	3518,32	5932,24	6617,53	3518,32	5932,24	6617,53
$\Delta V\ (KN)$	1600,77	681,83	559,82	1098,79	421,98	281,74
$\tilde{V}\ (KN)$	2580,10	5250,41	6057,71	2580,10	5510,26	6335,79
α	0.733	0.733	0.733	0.733	0.733	0.733
$\alpha V\ (KN)$	2580,10	4350,31	4852,85	2580,10	4350,31	4852,85
Reduction in V (%)	**26,67**	**11,49**	**8,46**	**26,67**	**7,11**	**4,26**

Table 6. Fixed and flexible base shear force reduction in response spectrum method retained by the RPA99 provisions.

	Response spectrum procedure					
	NIST-2012			Givens-2016		
	R+3	R+7	R+11	R+3	R+7	R+11
$V\ (KN)$	4478,52	7551,22	8423,53	4478,52	7551,22	8423,53
$\Delta V\ (KN)$	1192,18	448,08	401,47	731,52	305,52	236,05
$\tilde{V}\ (KN)$	3286,33	7103,15	8022,06	3746,99	7245,7	8187,48
Reduction in V (%)	**26,62**	**5,93**	**4,77**	**16,33**	**4,05**	**2,80**

Table 5 and 6 clearly shows that reduced base shear forces from the two methods are in good agreement whereas the reduction rate is important and relates to the RPA99 equivalent static method. Indeed, the latter considers the total structural weight in the design of base shear force, which, consequently, leads to an important fixed base shear force, unlike to most of seismic codes retaining only 70% of the total structure's weight, to reflect the structural weight mobilized by the first mode of the structure. In addition, disparity in the rates refers partially to regulatory aspects and dynamic effect neglected in the equivalent static method.

Conclusion

Seismic design of buildings is mostly carried out with the assumption of perfect embedding at a rigid base. Unlike buildings on fixed base, flexible base has an obvious effect on the seismic buildings' behavior and offers a prominent reduction in the internal forces produced within the superstructure, especially for massive low-rise buildings. As a first observation, results found in the study show that SSI effects has a beneficial influence on the structural response and reflect what one would expect from the analysis of coupled site-structure systems relative to the corresponding fixed-base ones.

It is clearly observed, in the light of the results, that flexible-base structural response allows reducing amplification expected from site effects, and the fixed base hypothesis retained by the RPA99 and by the most of seismic codes associated with site effects leads, overall, to an over estimation of the structural response and hence of the seismic damage.

Scientific Ethics Declaration

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

Acknowledgements or Notes

* This article was presented as an oral presentation at the International Conference on Technology, Engineering and Science (www.icontes.net) held in Antalya/Turkey on November 16-19, 2023.

References

Asce. (2007). Minimum design loads and associated criteria for buildings and other structures. *American Society of Civil Engineers, 1877*, 7-16.

Avilés, J., & Pérez Rocha, L. E. (2011). Use of global ductility for design of structure-foundation systems. *Soil Dynamics and Earthquake Engineering, 31*(7), 1018–1026.

Givens, M. J., Mylonakis, G., & Stewart, J. P. (2016). Modular analytical solutions for foundation damping in soil-structure interaction applications. *Earthquake Spectra, 32(*3), 1749–1768.

NIST GCR. (2012). Soil-structure interaction for building structures. *National Earthquake Hazards Reduction Program (NEHRP), 12.*

Jennings, P., & Bielak, J. (1973). Dynamics of building-soil interaction. B*ulletin of Tile Seismological Society of America, 63*(1), 9–48.

Pais, A., & Kausel, E. (1988). Approximate formulas for dynamic stiffnesses of rigid foundations. *Soil Dynamics and Earthquake Engineering, 7*(4), 213–227.

RPA99. (2003). Règles Parasismiques Algériennes, D.T.R. –B.C. 2.48. *National Center of Earthquake Applied Research (CGS).*

Stewart, J. P., & Fenves, G. L. (1998). System identification for evaluating soil-structure interaction effects in buildings from strong motion recordings. *Earthquake Engineering and Structural Dynamics, 27*(8), 869–885.

Veletsos, A. S., & Wei, Y. T. (1971). Lateral and rocking vibration of footings. J*ournal of the Soil Mechanics and Foundations Division, 97*(9), 1227–1248.

Veletsos, A. S., & Meek, J. W. (1974). Dynamic behaviour of building-foundation systems. *Earthquake Engineering & Structural Dynamics, 3*(2), 121–138.

Wolf, J. P. (1985). *Dynamic soil-structure interaction*. New Jersey: Prentice-Hall Inc.

Author Information

Adnane Brahma
University of Science and Technology Houari Boumediene (USTHB)
Algiers, Algeria
Contact e-mail: abrahma@usthb.dz

Mohamed Beneldjouzi
University of Science and Technology Houari Boumediene (USTHB)
Algiers, Algeria

Mohamed Hadid
National High School of Public Works (ENSTP)
Algiers, Algeria

Mustapha Remki
Earthquake Engineering Applied Research Center (CGS)
Rue Kaddour Rahim, BP 252, Hussein Dey, Alger, 16040
Algeria

To cite this article:

Brahma, A., Beneldjouzi, M., Hadid, M., & Remki, M. (2023). Evaluation of the seismic response of reinforced concrete (RC) buildings considering soil-structure-interaction effects. *The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 26,* 49-59.