ISBN 978-989-9121-17-1
46th ISTANBUL-TURKEY International Conference on "Advances in Science & Technology"
(IICAST-22)
Dec. 15-16, 2022 Istanbul (Turkey)

Influence of Soil Behavior Laws on The Seismic/Dynamic Response of Soil Profiles- Study Case

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Abstract**:** *Seismic wave amplitudes increase significantly as they pass through soft soil layers near the earth's surface. This phenomenon is called "amplification" or "site effects" considered an important factor that affects the extent of damage to structures. It is crucial that the site effect be taken into account when designing structures on soft soils. The parameters of ground motion surface acceleration and the amplification factor of a given site can be estimated by numerical analyzes (analytical models), as well as experimental tests. Numerical analyzes require knowledge of the geometry of all soil layers from surface to bedrock, their dynamic properties (e.g. density, wave velocity, damping), and incidental movements (seismic recordings at Substratum). The calculation of the seismic response of a given site by numerical analyzes is obtained by using laws of behavior that correspond to the nature of each soil layer (sand, clay, marl). These laws of behavior vary from one calculation code to another and from one type of analysis to another.*

This study investigates the influence of soil behavior laws on DEEPSOIL code for three types of analysis (linear; equivalent linear and nonlinear) on the response of soil profiles under the effect of a seismic excitation in order to be able to quantify the effects of the site and the dynamic amplification.

Keywords: *Soil profiles; Laws of behavior; Earthquake; Linear equivalent; non-linear.*

1. Introduction

Throughout the world, there are different approaches for evaluating soil responses (linear approach, equivalent linear approach and non-linear approach). Several laws of behavior have been proposed and used by researchers and professors to arrive at a final result for use in unidimensional analysis.

The linear method is used when the amplitude of the cyclic shear strain γ_c is lower than 10^{-5}, the behavior of the soil around a given effective stress state is reasonably linear elastic. The problem of finding its constitutive law is then reduced to that of finding the initial shear modulus G_0 which depends above all, for a given soil, on the initial void index and the average effective stress. We must then solve problems of wave propagation in an elastic linear and heterogeneous environment.

The equivalent linear method calculates the response of a one-dimensional, horizontally stratified soil column to the vertical propagation of shear waves (SV). It gives an approximate account of the behavior of soils under cyclic loading. The method of resolution of the linear equivalent is an iterative procedure, where one evaluates with each iteration for each layer of ground, of the viscoelastic characteristics linear equivalent starting from the curves of degradation of shear modulus G and the increase in hysteretic damping experimentally measured.

The non-linear dynamic responses of soils and rocks have been extensively studied in the laboratory since the sixties. These experiments also highlight the hysteretic behavior of soils and rocks subjected to quasi-static and cyclic stresses. These behaviors, being intrinsic to geo-mechanical materials, require to include them in the

https://doi.org/10.17758/DIRPUB13.DIR1222164

numerical models to provide precise and as exact results as possible. There are generally three indicators of non-linear behavior. First, a shift of the resonance frequency towards low frequencies, which has been clearly observed in many soil samples through one-dimensional experiments and on in-situ measurements. Second, a generation of harmonics inducing an amplification of high frequencies. And thirdly, the hysteretic damping which leads to a decrease in the amplitude of the wave. This decrease is generally attributed to the presence of dislocations in the metals, small cracks or contacts between the grains of the geo-materials [1].

The objective of this work is the evaluation of the influence of the choice of soil behavior laws on the dynamic response of soil profiles using the DEEPSOIL v7.0 [2] computer code.

2. Presentation of the Studied Site

2.1. Location

The studied site is located at a place called "FOES" which is part of the fragmentation of lot N°07 located in the city of Boumerdès in Algeria which was hit by a devastating earthquake on May 21, 2003.

From the morphological point of view, the site object of this study presents a stable state and a practically flat topography.

Fig. 1: Geographical location of the studied site.

2.2. Geotechnical Characteristics of the Soils of the Studied Site

In order to identify the exact lithology of the studied site, a 25m deep coring borehole was implanted and executed. The borehole carried out was equipped with SPT and piezometer tests to verify the presence or absence of groundwater at the site.

TABLE I: SPT test results

Depth (m)	Number of raw hits			
	N0	N1	N2	N=N1+N2
3,00 to 3,45	12	15	18	33
6,00 to 6,45	7	9	10	19
9,00 to 9,85	7	8	12	20
12,50 to 12,95	13	15	17	32
15,00 to15,45	24	24	34	58
18,80 to 18,95	40	42	45	87
22,80 to 23,25	16	22	28	50
24,55 to 25,00	22	30	33	63

The shear wave propagation velocity Vs for each soil type was obtained using correlations with SPT test.

- For Sand: $Vs=100.5\ N^{0.29}$ (1) [3]
- For Clay: $Vs = 132\ N^{0.271}$ (2) [4]
- For Silts $Vs = 145\ N^{0.178}$ (3) [4]

In small deformations, the shear modulus G_{max} is related to shear wave propagation velocity Vs by the following relation: $G_{max} = \rho V_S^2$ (4) [5]

where ρ is the density of soil.

Examination of the section of the core drillings revealed the lithological succession and the characteristics of the soil layers are given below:

TABLE II: Characteristics of the soil layer of FOES site.

Layers	Depth (m)	ρ(KN/m^3)	G (KN/m^2)	Vs (m/s)
Silts and Sand	0.00- 4.30	20	148829,1343	270,18
Silt and fine sands	4.30- 11.70	19	118300,6893	247,14
Sands and silts	11.70- 17.40	17	130646,87	274,57
Medium to coarse sands	17.40-20.20	20	274545,46	366,96
Plastic weathered marl	20.20-21.30	20,6	1683928,09	895,49
compact marl (Bedrock)	21.30- 25	22		>800

3. One-Dimensional Analysis of Seismic Ground Response of Foes Site

One-dimensional soil response analyzes are based on the assumption that all boundaries are horizontal and that the response of a soil deposit is caused primarily by S-H waves, propagating vertically from the underlying bedrock. For one-dimensional soil response analysis, soil and bedrock surfaces are assumed to be infinite in the horizontal direction.

From the thicknesses and the geotechnical and geophysical properties of the soil layers and using the DEEPSOIL software, an analysis of the dynamic response of the Foes site to seismic excitation was carried out.

The seismic excitation was introduced as an accelerogram recorded at the bedrock during the earthquake of May 21, 2003 which occurred in Boumerdes.

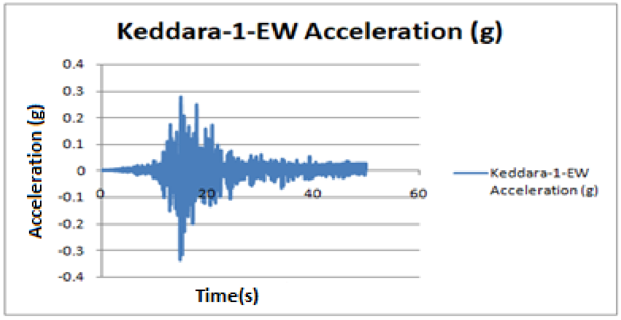


Fig. 2: E-W component of the Boumerdes earthquake acceleration recorded at station 1 in Keddara (PGA = 0.33g at 15.195s)

The analysis of the dynamic response of the soil profile was made by considering the three types of soil behaviour: linear, equivalent linear and nonlinear.

A variety of models are available for DEEPSOIL analyses. These models include: a) Equivalent Linear, b) Hyperbolic (MR, MRD, DC), c) a Non-Masing Hyperbolic model (MRDF), and d) Porewater Pressure Generation and Dissipation. [2]

The nonlinear analysis was performed considering the pressure-dependent Hyperbolic model for all soil layers. The modified hyperbolic model, developed by (Matasovic, 1993) [6], is based on the hyperbolic model by (Konder and Zelasko, 1963) [7], but adds two additional parameters Beta (β) and s that adjust the shape of the backbone curve:

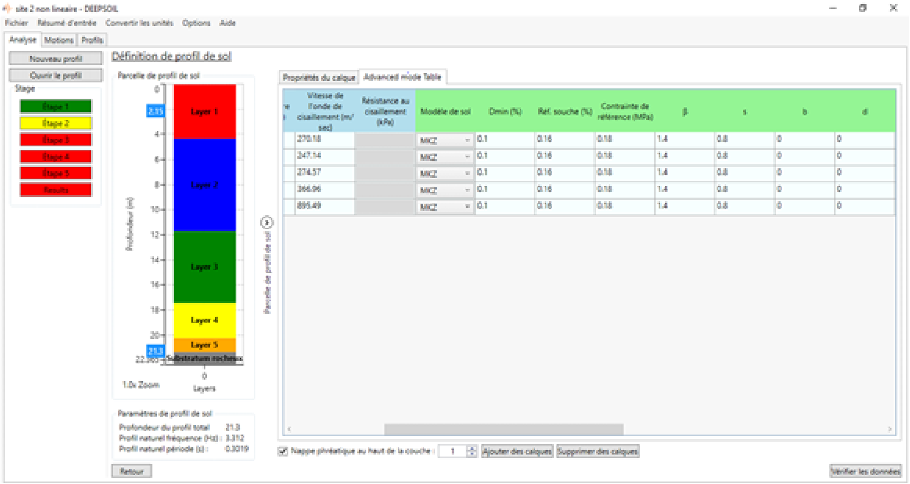
$$\tau= (G_0.\gamma)/(1+\beta(\gamma/\gamma_r\ )^\wedge s\ ) \qquad (5)$$

where G_0 = initial shear modulus, τ = shear strength, γ = shear strain. Beta, s, and γ_r are model parameters. There is no coupling between the confining pressure and shear stress.

DEEPSOIL extends the model to allow coupling by making γ_r confining pressure dependent as follows [8]:

$$\gamma_r = \text{reference Strain } (\sigma'_v / (\text{reference Stress})\ \hat{}\ b \qquad (6)$$

where σv' is the effective vertical stress. Ref. stress is the vertical effective stress at which γ_r= Ref. stress.



Vitesse de l'onde de cisaillement (m/sec)	Résistance au cisaillement (kPa)	Modèle de sol	Dmin (%)	Réf. souche (%)	Contrainte de référence (MPa)	β	s	b	d
270.18		MKZ	0.1	0.16	0.18	1.4	0.8	0	0
247.14		MKZ	0.1	0.16	0.18	1.4	0.8	0	0
274.57		MKZ	0.1	0.16	0.18	1.4	0.8	0	0
366.96		MKZ	0.1	0.16	0.18	1.4	0.8	0	0
895.49		MKZ	0.1	0.16	0.18	1.4	0.8	0	0

Paramètres de profil de sol

Profondeur du profil total	21.3
Profil naturel fréquence (Hz) :	3.312
Profil naturel période (s) :	0.3019

☑ Nappe phréatique au haut de la couche : 1

Fig. 3: Numerical simulation of the nonlinear analysis of the soil profile studied with DEEPSOIL.

4. Results and Discussion

The results of the dynamic response of the FOES site obtained from the different analyzes in the time domain in terms of surface acceleration are presented in Figure 4.

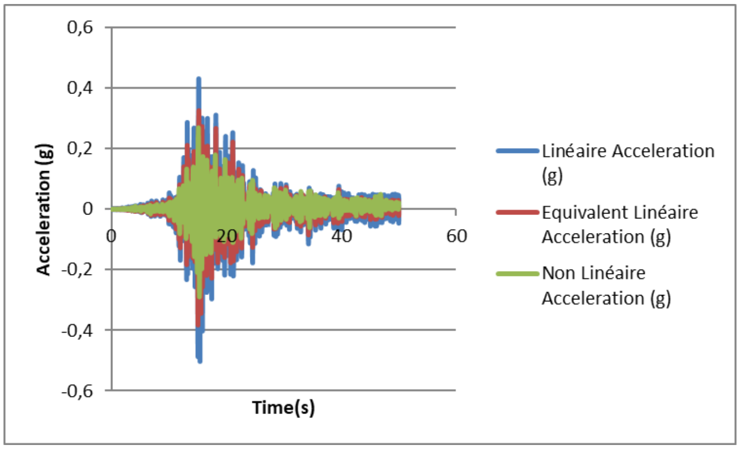


Fig. 4: Dynamic response in terms of surface acceleration for the three types of analysis.

The linear analysis of the dynamic response shows an increase in the maximum acceleration at the surface PGA= 0.5g at t=15.4 s compared to the acceleration induced at the base PGA= 0.33g at t=15.195s, which means a significant amplification of the seismic movement in a higher time interval.

As for the equivalent linear analysis, this shows an increase in the maximum surface acceleration PGA= 0.38g at t=15.05 s compared to the acceleration induced at the base PGA= 0.33g at t=15.195s, which means an amplification of the seismic movement in a lower time interval. While the non-linear analysis gives as results a decrease in the maximum surface acceleration PGA = 0.28g at t = 15.29s compared to the acceleration induced at the base, which means a de-amplification of the seismic movement in a higher interval.

The results of the frequency content of the dynamic response of the FOES Site in terms of spectral acceleration, Fourier amplitude are represented in the following figures.

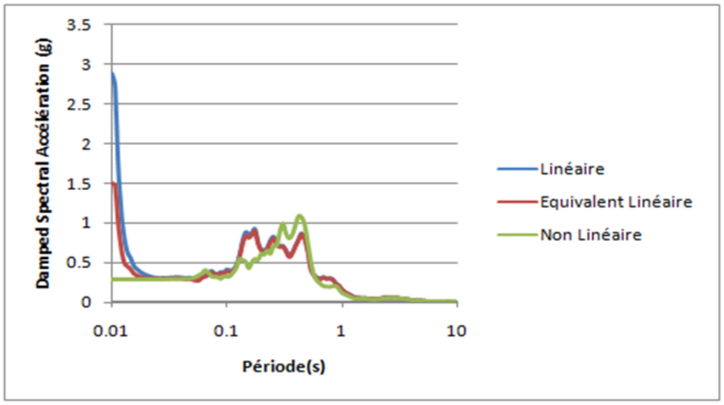


Fig. 5: Damped response acceleration spectra of the Foes site.

The damped response spectrum of the acceleration shows an amplification of the spectral acceleration for the three behavior laws.

The linear and equivalent linear behavior of the soils of the FOES site lead to a spectral acceleration of the order of 0.8g in a period range ranging from 0.1s to 0.5s. While the nonlinear behavior results in a spectral acceleration of the order of 1.1g in a period range ranging from 0.3s to 0.5s.

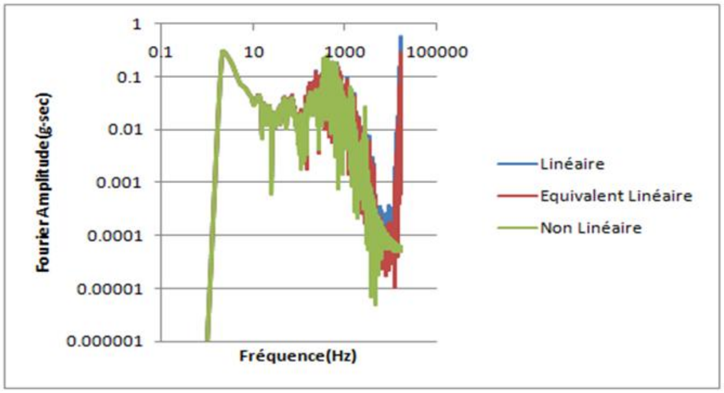


Fig. 6: Fourier amplitude response spectrum of the FOES site.

The Fourier amplitude response spectrum shows that the three soil behavior laws lead to amplification of amplitude and motion for frequencies ranging from 2Hz to 10Hz.

5. Conclusion

From the results obtained, it can be concluded that the dynamic response of the site depends essentially on the laws used to describe the behavior of the soils of the latter.

The behavior laws incorporated in the DEEPSOIL software require several parameters, these may not exist in the soil reports so we use the correlation relationships with the available parameters to determine them.

The results obtained in the time domain of the dynamic response of the site of FOES to the excitation of the earthquake of May 21, 2003 show an amplification of the acceleration at the surface for the linear and linear equivalent behaviors and a de-amplification of the acceleration at the surface for the nonlinear behavior.

While the results obtained in the frequency domain show an amplification of the spectral acceleration for the three behavior laws, which implies the necessity of the combination of the results for the estimation of the site effects.

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