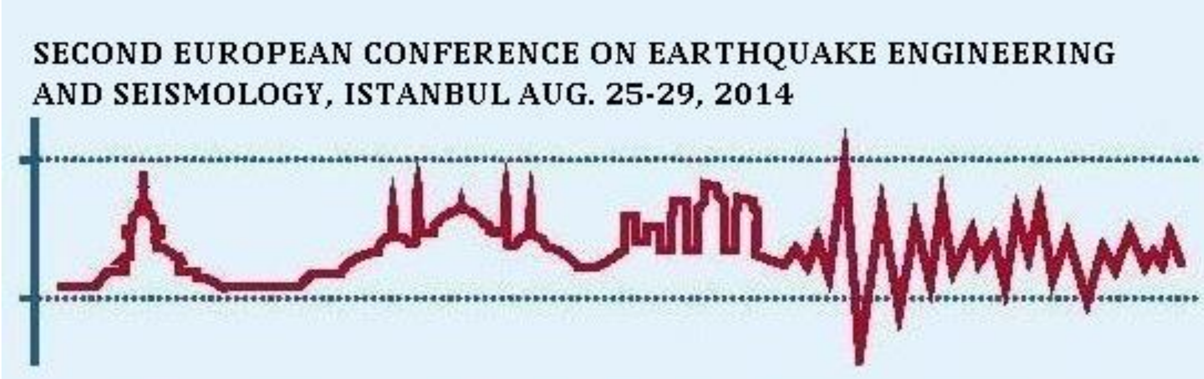

Site response analysis models: Case study from sites near Algiers city.

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Abstract

It is well known that local site conditions can play an important role in the amplification of ground motion in a given area. In fact, local geological and soil conditions shape the intensity of ground shaking and consequently influence earthquake damages. Namely, site conditions affect the amplitude, the frequency content and the duration of ground motion. Damages induced by site effects depend on the topographic irregularities, the characteristics of the input motion and the subsurface material proprieties. It is established that site effects should be considered as crucial input in the damage evaluation process and thus need accurate evaluation. Among different approaches used for modeling and analyzing site effect, the one-dimensional ground response analysis method is particularly flexible and can be applied easily as in this study to estimate site amplification under earthquake shaking. In this study, site effect is characterized by four main parameters, namely shear modulus, density, velocity of shear waves propagation and soil damping ratio. Then these parameters are input in the one–dimensional ground response analysis to estimate the transfer functions required to calculate the ground amplification. This study focuses on amplification peaks observed for similar frequency between earthquake and soil nature. The method used allows us to derive realistic results which can be used to improve local seismic hazard values.

Introduction

Recent seismic activity in northern Algeria, especially during the last 50 years, is characterized by the occurrence of several damaging earthquakes. El Asnam region suffered the most destructive and damaging earthquakes in northern Algeria, namely the 1954 September 9Ms 6.8 and the 1980 October 10 Mw 7.3 earthquakes. The most significant and recent event was the 2003 May 21 Zemmouri earthquake with moment magnitude Mw 6.9, which was located about 50 Km Northeast of Algiers city. The seismicity in northern Algeria is the result of the compressional movement between African and Eurasian plates. This seismicity is mainly located in Tellian Atlas.

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In this context, there is increasing interest in seismology and seismotectonics among Algerian scientific community, especially in seismic risk assessment to urban area and its possible reduction. The study region includes three sites from Algiers city. As seen in Fig. 1, these sites are Bab el Oued, El Mouradia, and Dar El Beida.

Synthetized soil profiles and accelerations are input in EERA software to analyze the reaction of soil stratigraphic log under seismic movement at rock level to determinate different output in soil surface. Obtained results are presented as acceleration data corresponding to the surface and soil layers of profile, as well as amplitude report (the function of transfer of the basement). The function of transfer defines the relation between the properties of soil and amplification factor, and its considered as a filter surface layer. It is therefore described by soil properties, as damping factor, factor of the thickness of the layer, of shearing module, the density and velocity of seismic waves. The transfer function is converting the rock input movement to soil movement output.

The theory considers the responses associated with wave propagation vertical shear associated with linear viscoelastic system. This system is continuous and composed with N horizontal layers extending to infinity with a bottom layer modeled as a half space. In this model, layers are homogeneous and are characterized by its thickness *h*, its density ρ, a shear modulus *G* and a damping factor ξ.

Figure 1 Positions of drilling at Algiers city

Methodology

We expect the maximum amplification of ground movements to occur near the fundamental frequency. Therefore, thicknesses of soil layers are important when estimating the effect of the total stratigraphic well log of site soil ground movement. The structure of shear wave velocity affects the frequency when a problem of maximal amplification is encountered. To evaluate earth response, the transfer functions can be used to express various response parameters, such as displacement, velocity, acceleration, shear stress and shear strain, calculated for a motion parameter such as the acceleration input in the bedrock. This approach is limited to the analysis of linear systems. The nonlinear behavior can be approached by using an iterative procedure with equivalent properties of linear soil. A known movement of substrate (entry) is represented by a Fourier series, usually using fast Fourier transform. Each term of bedrock Fourier series (input) motion is multiplied by the transfer function to produce the Fourier series of soil surface movement (output). Soil surface movement (output) can be expressed in the time domain using the inverse fast Fourier transformation. Thus, the transfer function defines how the movement of the rock in each frequency (input) is amplified or de- amplified by the soil well log. A key to the linear approach to earth response analysis is the evaluation of the transfer functions.

Description of the software EERA

The EERA (Equivalent -linear- Earthquake Response Analysis) software (e.g. Fig. 2) was developed in 1998 using an equivalent linear code (Bardet et al. 2000). This later operates similarly to SHAKE / SHAKE91 (Schnabel and al, 1972; Idriss and Sun, 1991). EERA was first developed using FORTRAN 90. EERA calculates answers of dimensional ground for a system of infinite horizontal homogeneous layers which are subject to viscoelastic shear waves traveling vertically. The program uses a continuous solution of the wave equation adapted to transient movement via the fast Fourier transform algorithm. The non-linearity of the shear modulus and damping is approximated by the use of equivalent linear soil properties. The obtained values are compatible with the actual stress in each layer. EERA calculates the response of a system of horizontal layers soil - rock submitted to ride waves and transient vertical shear. It assumes that the cyclical behavior of soils can be reproduced using an equivalent linear model, this hypothesis has widely adopted in seismic and geotechnical engineering (Idriss and Seed, 1968; Seed and Idriss, 1970, Kramer, 1996). Simplified geometry and behavior of cyclic material is assumed when using EERA.

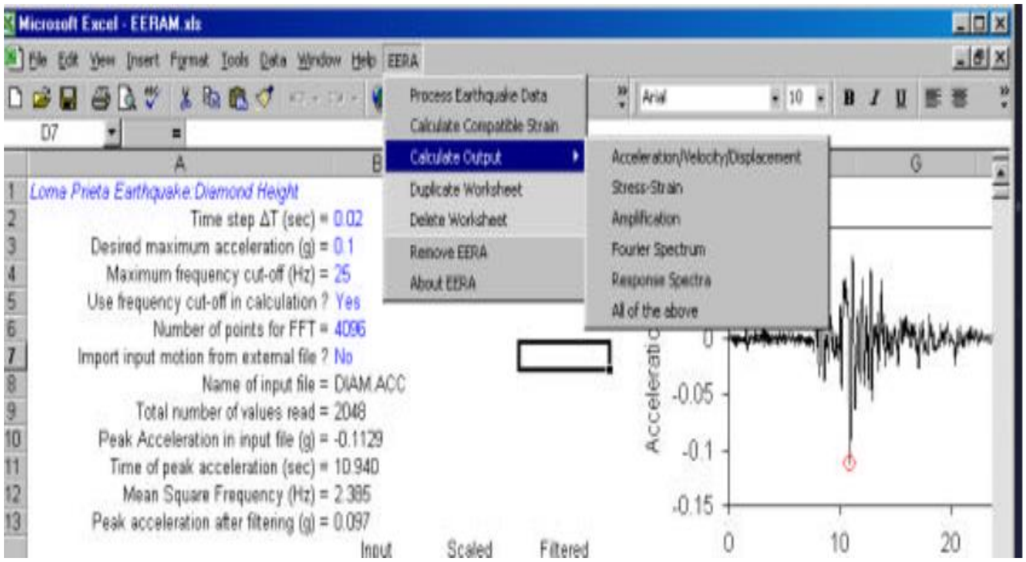


Figure 2. Example of the drop down of the EERA software

Presentation of the Accelerations and data profiles of soil at the studied sites

Acceleration

For convenience, acceleration was calibrated on the1989 Loma Prieta earthquake occurred on October 17, with a magnitude *Ms* = 7.1. This earthquake was recorded on two remote stations located at 7 Km (Carolitos) (Fig. 3) and 61.3 km from the fault (Diamond Height) (Fig. 4).

Station Carolitos

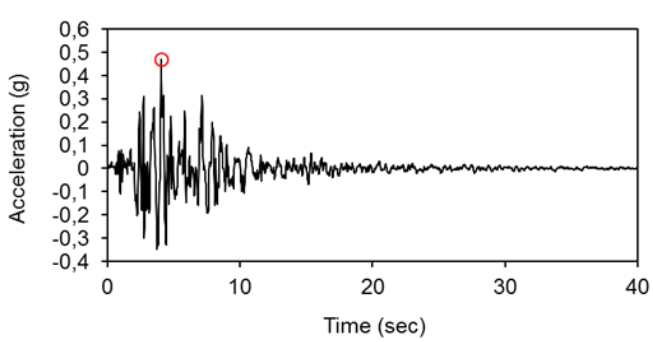


Figure 3 Acceleration recorded on Carolitos site

Acceleration Maximal (g): 0.47
Velocity Maximal (cm/s): 45.25
Displacement Maximal (cm): 20.30

Station of Diamond Height

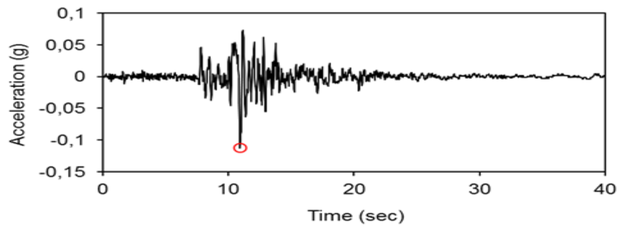


Figure 4 Acceleration recorded on Diamond Height site

Acceleration Maximal (g): 0.11
Velocity Maximal (cm/s):1 4.23
Displacement Maximal (cm): 04.20

Soil Profile

Different profiles of soil were synthesized from holes drilled at the micro-zoning for the region of Algiers just after the 2003 Boumerdes earthquake. Geotechnical parameters were studied using boreholes cores provided by different institutions (LNHC, LCTP). Different shear rates at each layer were calculated from geophysical test records (Down-hole). The table below lists the data of each soil profile used in our study.

Table 1. Profile used in Bab-El-Oued site

Thicknesses of the layers (m)	Damping (%)	Density (KN/m^3)	Shear velocity (m/s)	Effective vertical stress KPa	Maximum shear modulus G_{max}(MPa)
0,00 Vegetal ground 3,00	3	12,50	320,00	18,75	130,48
Sand 05,00	3	16,50	500,00	78,75	420,49
Rock	3	20,00	1200,00	120	2935,78

Table 2. Profile used in Dar El Beida site

Thicknesses of the layers (m)	Damping (%)	Density (KN/m^3)	Shear velocity (m/s)	Effective vertical stress KPa	Maximum shear modulus G_{max}(MPa)
0,00 Silt/Clay 2,00	3	16,50	210,00	16,50	74,17
Silt/Clay 07,00	3	17,00	270,00	92,85	127,07
Clay/Marne/ Trace of sandstone 8,00	3	18,00	330,00	224,70	199,82
Sand/Sandstone 10,00	3	19,66	430,00	395,00	370,56
Rock	3	20,00	800,00	493,00	1304,79

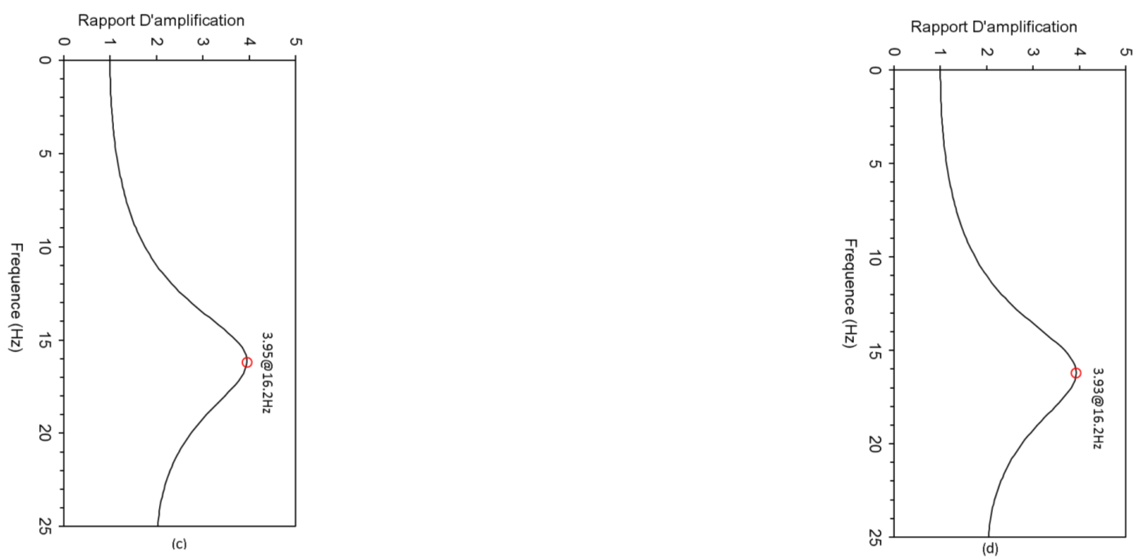
Table 3. Profile used in El Mouradia site

Thicknesses of the layers (m)	Damping (%)	Density (KN/m^3)	Shear velocit y (m/s)	Effective vertical stress KPa	Maximum shear modulus G_{max}(MPa)
0,00 Bank 4,00	3	12,50	180	25	41,28
Clay/Silt Sand/Gravel 13,00	3	16,50	310,00	157,25	161,64
Medium to Rude Sand / Sandstone 13,00	3	19,00	420,00	392,29	353,52
Schist / sandstone(Rock)	3	20,00	669,00	520,00	970 ,64

Results and Discussion

This study compares accelerations of real rock and accelration of ground surface at Algiers city. Detailed soil models were constructed from geophysical and geotechnical methods. Equivalent linear 1-D ground response analysis of ground motion earthquake carried in our study using EERA software can be applied to a reference historic earthquake. In our case we chose the 1989 Loma Prieta earthquake. Both accelerations recorded at the surface and the interface soil-rock was used to calculate site response in Bab El Oued, Dar El Beida and El Mouradia. At the site of Bab El Oued (Fig.5) we observe peak acceleration at ground level (PGA) approximately equal to that observed for rock; besides rock and observed amplifications are similar, which results in made that the soil is not amortized. For the site of Dar El Beida (Fig. 6) the PGA in surface is about four times the PGA observed for rock soil, difference between the peak amplification results is due to the amortization of the site. The site of El Mouradia (Fig.7) results in a PGA at surface equal to about one and half time that observed for rock soil and the difference between peaks of amplification is due to the amortization of the site. In this study, EERA software is used to summarize the results. (Tables 4 and 5). These results should be evaluated in detail to produce an accurate representation of the actual response of the ground motion. In particular, soil model may be not suitable or does not include important details. It can also generate a variety of three-dimensional effects which influences the movements of registered soil. EERA model is based on two-dimensional planar layers and the existing geometric variation in reality may be not reflected in the EERA model. Dispersion and concentration of seismic energy can occur together. In addition, the resonance of the waves crossing well logs soil can influence EERA ground motion model due to the geometry of the basin.

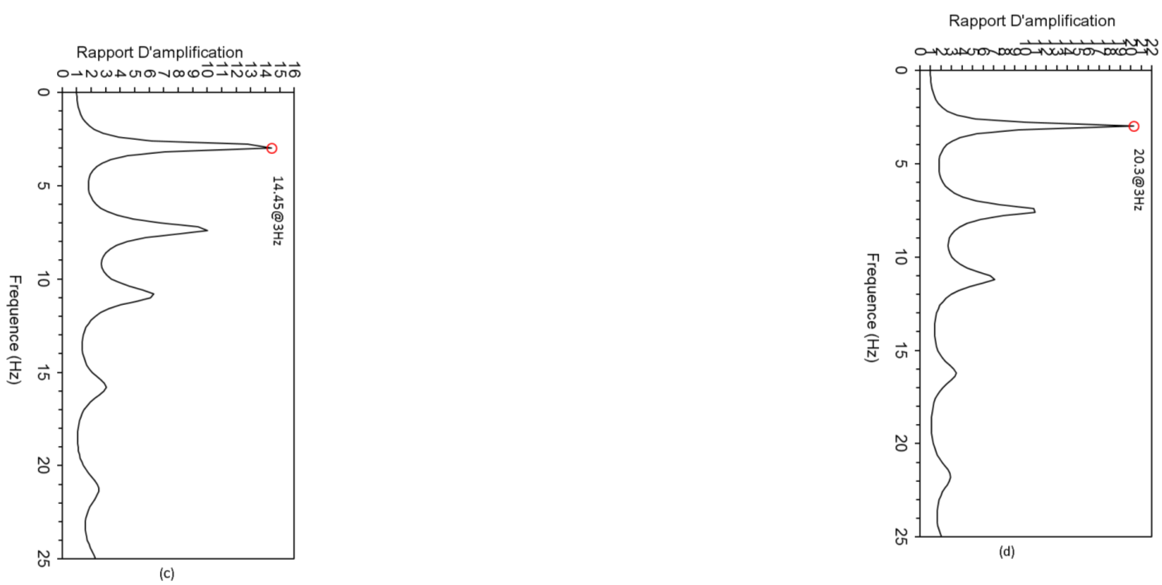
Acceleration recorded at borehole logs in Bab El Oued (a) Diamond Height, (b) Carilitos



Transfer function recorded at Bab El Oued (c) Diamond Height, (d) Carilitos

Figure 5. Result of Bab El Oued site

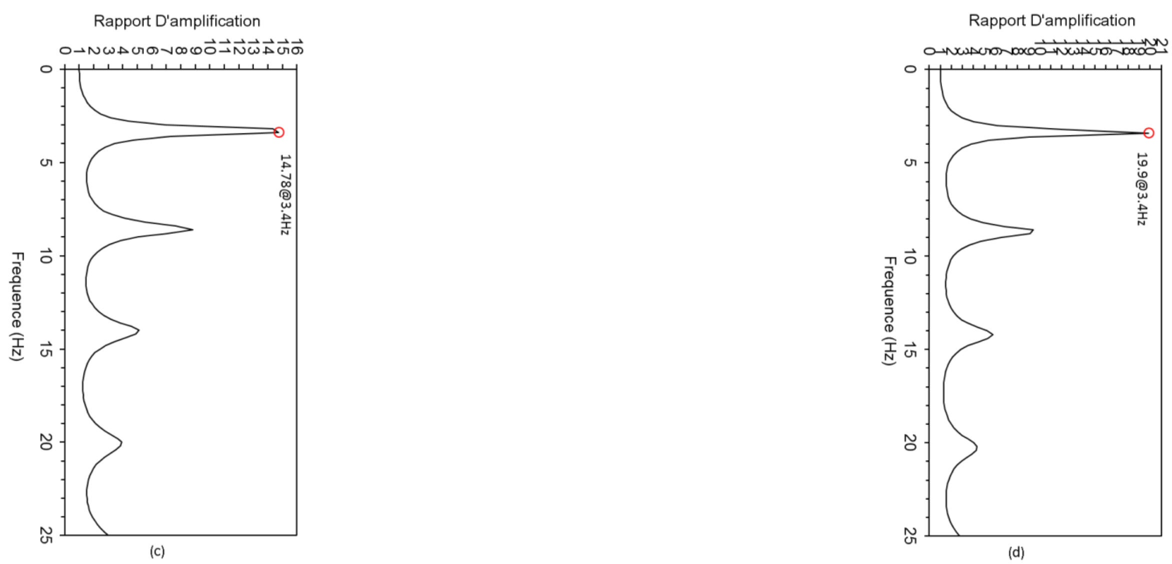
Acceleration recorded in borehole logs at Dar El Beida (a) Diamond Height, (b) Carilitos



Transfer function recorded at Dar El Beida (c) Diamond Height, (d) Carilitos

Figure 6 Result at Dar El Beida site

Acceleration recorded in borehole logs at El Mouradia (a) Diamond Height, (b) Carilitos



Transfer function recorded at El Mouradia (c) Diamond Height, (d) Carilitos

Figure 7 Result at El Mouradia site

Table 4. Analysis results of equivalent linear seismic accelerations using algorithms EERA. Table of PGA values .

Bab El Oued	PGA (g) @ 08 m	PGA (g) @ Surface	PGA (g) Theoretical
Diamond Height	0.1	0.105	0.11
Coralitos	0.1	0.15	0.47
Dar El Beida	PGA @ 30 m	PGA @ Surface	PGA Theoretical
Diamond Height	0.1	0.4	0.11
Coralitos	0.1	0.36	0.47
El Mouradia	PGA @ 27 m	PGA @ Surface	PGA Theoretical
Diamond Height	0.2	0.32	0.11
Coralitos	0.2	0.30	0.47

Table 5. Analysis results of equivalent linear seismic accelerations using algorithms EERA. Table of maximum amplification ratio and the frequency.

Bab El Oued	Maximum Amplification Frequency (Hz)	Maximum Amplification Ratio
Diamond Height	16.2	3.95
Coralitos	16.2	3.93
Dar El Beida	Maximum Amplification Frequency (Hz)	Maximum Amplification Ratio
Diamond Height	3	14.45
Coralitos	3	20.3
El Mouradia	Maximum Amplification Frequency (Hz)	Maximum Amplification Ratio
Diamond Height	3.4	14.78
Coralitos	3.4	19.9

Conclusion and recommendation

Two acceleration records were used to assess soil movement response for three selected sites from Algiers city that are Bab El Oued, Dar El Beida and El Mouradia. The earthquake magnitude used is MS = 7.1 both records accelerations are distant from 7.1 and 61.3 Km compared to measuring stations. The terrain models generated are used in the analysis of different sites with EERA. This study indicates that procedures used to evaluate the site response of deep soil sites do capture most of the site amplification feature. It also suggests that the procedures need to be evaluated with as much detail as possible in order to produce an accurate representation of the actual ground-motion response. This study also shows that more detailed analysis (e.g. , 3D) how deep soil sites respond to ground shaking is necessary to help engineers and scientists understand the amplification of ground movements in the Algiers city

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