INFLUENCE OF A LOW RESISTANCE LAYER ON SEISMIC SOIL RESPONSE USING CYBERQUAKE

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SUMMARY

In this paper, numerical investigations are conducted to globally analyse the impact of a low resistance layer at depth and to show the relative effects of several factors on the seismic response of multilayered sediments. Two specific soil configurations are analysed : one fictitious profile where mechanical characteristics are progressively improving with increasing confining pressure and the second, a real soil column, presenting a layer of poor resistance at 15 meters depth. Five input motions, artificial signals and real acceleration recordings, having PGA varying from 2 to 3.5 m/s^2 were selected. The dynamic analyses are carried out using CyberQuake software. In order to show the ability of CyberQuake to improve ground motion simulations, comparisons are made with the well-known equivalent-linear approach.

INTRODUCTION

Seismic hazard assessment enables to characterise potential seismic aggressions that need to be taken into account when designing new structures or upgrading existing ones. At local scale, it requires three evaluations: the definition of reference seismic motions taking account of the specific soil conditions, the presence of seismogenic faults close to the sites, and the effects that could be induced by seismic tremors on the stability of the soils (e.g. landslides, liquefaction, settlement). Estimation of the local response of a site is therefore a key component of any analysis of local seismic hazard.

In regions of moderate seismicity like France, determination of lithological site effects using instrumental approaches cannot reproduce the non-linear soil behaviour that could affect the seismic motion at the top of near-surface deposits. Experimental results are currently obtained for low deformation levels and the direct transposition to strong motions is not recommended. The only way to truly take into account the non-linear behaviour of soils is numerical modelling.

Generally speaking, two types of numerical approach are available : the equivalent-linear methods and the cyclic elastoplastic models. The former are very appreciated and widely used by engineers because of their simplicity and the rapidity of calculations. They provide quite acceptable results in case of low to moderate shear strain ranges where irreversible settlements and liquefaction risk may be considered as weak. The elastoplastic models permit a better evaluation of soil response on a wide strain range. Following this way, a new simplified numerical approach has been proposed by Modaressi and his co-workers [Mellal and Modaressi, 1998; Modaressi *et al*., 1997; Modaressi *et al*., 1995] and implemented in CyberQuake. CyberQuake is a BRGM Software and has been developed by Modaressi and Foerster. It is optimised for one-dimensional geometry problems and it handles the main aspects of the soil behaviour with a constitutive model based on elastoplastic theory.

In this study, CyberQuake is used to simulate the response of horizontally layered soils, for both elastoplastic and equivalent-linear methods, the latter being very similar to the model implemented in SHAKE [Schnabel *et al*., 1972; Idriss and Sun, 1992]. The objective is to show the influence of a layer having poor mechanical

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characteristics and situated at depth. The defined soil columns are submitted to different input motions. Results are compared with those obtained with the equivalent-linear approach in order to illustrate some inadequacies of the latter.

2. DATA SELECTION

2.1. Soil profiles

Instead of assuming a given homogeneous soil column, we decide to treat a real case, which allows us to evaluate the performances of CyberQuake in every day engineering practice. The chosen sector lies in the Rhone Delta where previous studies has been conducted [Bour *et al*., 1998]. A special effort is necessary in this region because of the proximity of an active fault. Furthermore, numerous critical installations are edified on soils whose geometric and dynamic properties can strongly amplify seismic motions. On this area, a particular soil column has been chosen because it presents an alternance of weak and medium formations.

2.1.1. Geotechnical synthesis

To match as accurately as possible to the in-situ case, a complete geotechnical analysis is necessary. As often in practice, information on geotechnical properties of soils are not exhaustive. The main geotechnical parameters available on the site are presented in Table 1. They were derived from current geotechnical surveys and from a synthesis of drilling data extracted from the BRGM's Subsurface Database. The quantity and nature of the geotechnical data on the site are sometimes heterogeneous. We had, for example, no measure of shear-wave velocities, since no cross-hole test was available for the zone. The same holds for the relative densities. As described in Table 1, the materials overlying the Miocene gravels are mainly sandy backfill, fine silty sand and clay deposits after ten meters depth.

Table 1 : Geotechnical properties of studied soil formations

(NC = normally consolidated; Q_c = cone tip resistance from CPT; P_l = limit strength at pressiometer test; w = water content; C_c = coefficient of compressibility; Φ' = friction angle; C' = cohesion)

material	description	N_1 (SPT)	ρ (kN/m^3)	Q_c (MPa)	P_l (MPa)	w (%)	C_c (?)	Φ' (°)	C' (kPa)
Sandy backfill		10	17.9	3.5					
Silty sand	fine to coarse, NC, little compressible, little permeable	20	19.3	2 to 10	0.4 to 1.1	18 to 28	0.07	33	0
Clayey silt	compressible, with humus debris		17.8	3	0.35	30 to 50	0.24	15	
Gravel			21	> 50	> 3			37	0

2.1.2. Extrapolation for elastoplastic model

In CyberQuake, the constitutive model is based on elastoplasticity theory. It is a derivation of 3-D Hujeux model [Hujeux, 1985] with some improvements. A complete description can be found in Mellal [1998]. The elastoplastic behaviour law is defined by 12 parameters usually not directly available from geotechnical synthesis. Their determination is made possible, in some cases by direct calculation, or more currently by experience or by correlation between them [Modaressi and Lopez-Caballero, 1999; Lopez-Caballero, 1999]. Following this process, the geometrical and main mechanical properties presented in Table 2, were derived from geotechnical data in Table 1. The Crau Miocene gravels are defined as the seismic substratum of the zone. The water table is present in the sandy backfill layer at 1.5 meter depth. In order to compare the influence on the surface ground motion, of the clayey silt layer having poor mechanical characteristics, we consider a fictitious soil profile where this formation is more consolidated (Table 2).

The variation of shear modulus and damping ratio with distortion, known as G/D-γ curves, is an important feature of soil behaviour submitted to cyclic loading. Dynamic models must cover the whole range of strains that soil may undergo during a seismic event. In Figures 1 and 2 are presented respectively for sand and clay formations in both studied profiles, the curves giving the variation of the normalised shear modulus G/G_{max} and damping ratio D with distortion, obtained by the elastoplastic model. During the parameters determination procedure, it is necessary to check if the simulated G/D-γ curves are able to correctly reproduce the feature of the soil behaviour. This is made by comparing them with well-known average and limit curves, such as the one published by Seed & Idriss [1970] for sands according to relative density, and by Vucetic & Dobry [1991] for clays according to plasticity index. Readjustments of several parameters could be necessary to have better accordance with these reference curves. It can be seen on Figures 1 and 2, that computed curves are lying inside the standard limit curves, except for damping values corresponding to distortions higher than 10^{-3}.

Table 2 : Mechanical properties of real (profile n°1) and fictitious (profile n°2) soil columns

material	Thickness (m)	V_S (m/s)	V_P (m/s)	ρ (kg/m^3)	G/D-γ curves number
Sandy backfill	1.5	180	340	1 790	1
Sandy backfill	1	180	340	1 790	2
Silty sand	8.5	300	560	1 930	2
Clayey silt (n°1/n°2)	7	170 / 400	320 / 750	1 780 / 1 700	3 / 4
bedrock	½ space	800	1 500	2 100	elastic

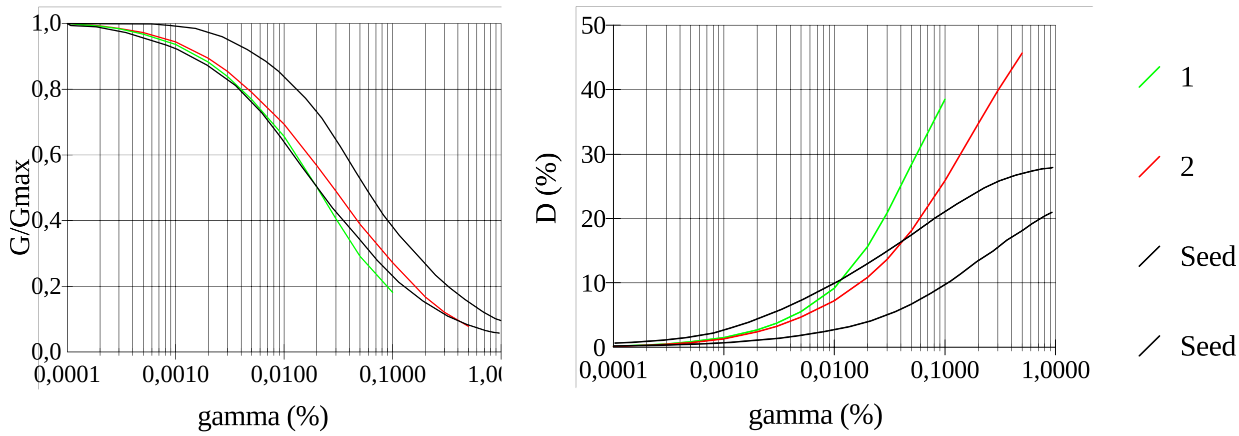

Figure 1 : Normalised shear modulus and damping ratio for sands

computed curves in red and green (according to numbers in Table 1)
limit curves from Seed & Idriss (1970) in black

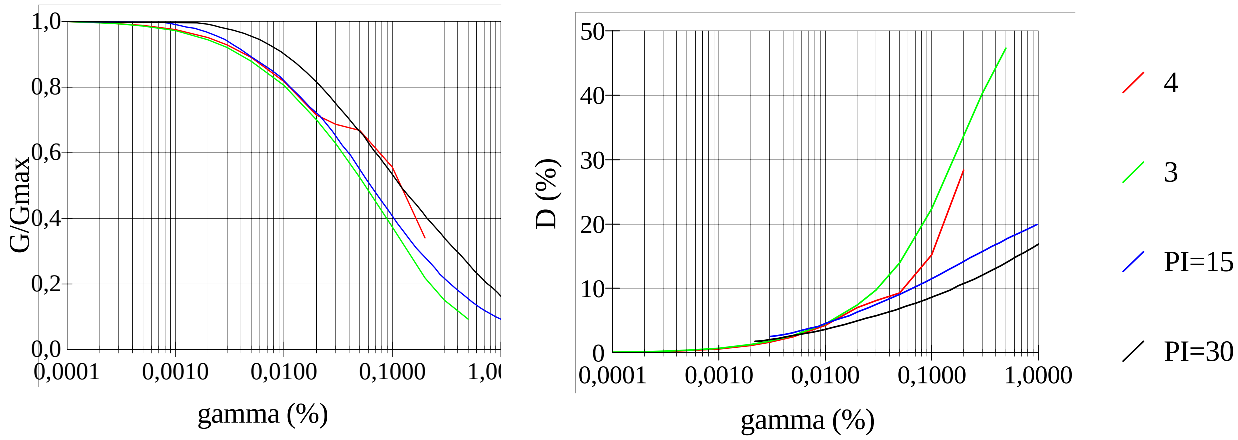

Figure 2 : Normalised shear modulus and damping ratio for clays

computed curves in red and green (according to numbers in Table 1)
PI curves from Vucetic & Dobry (1986) in black and blue

2.2. Input motions

To characterise incident bedrock motion, several accelerograms were selected: both artificially generated signals and real time histories. The synthetic accelerograms are obtained by direct application of the SIMQKE program [Gasparini & Vanmarcke, 1976], which generates statistically independent artificial acceleration time histories, whose response spectra "match", by iteration, a specified smooth response spectra. Natural accelerograms are taken from Turkish and Central America earthquakes. These events were chosen because their characteristics (magnitude and focal distance) are supposed to be similar to those associated with seismic sources in South of France. Characteristics and plots and of input motions are respectively given on Table 3 and Figure 3.

Table 3 : Characteristics of input accelerograms

number	origin (date)	M	dist. (km)	PGA (m/s^2)	main freq. (Hz)
1	Costa Rica (07.08.93)	5.0	25	2.1	8
2	Turkey (07.18.79)	5.2	15	3.2	5.5
3	Turkey (08.19.76)	5.0	11	3.5	2.2 and 4.2
4	synthetic			2.5	7 to 9
5	synthetic			2.0	4 to 7

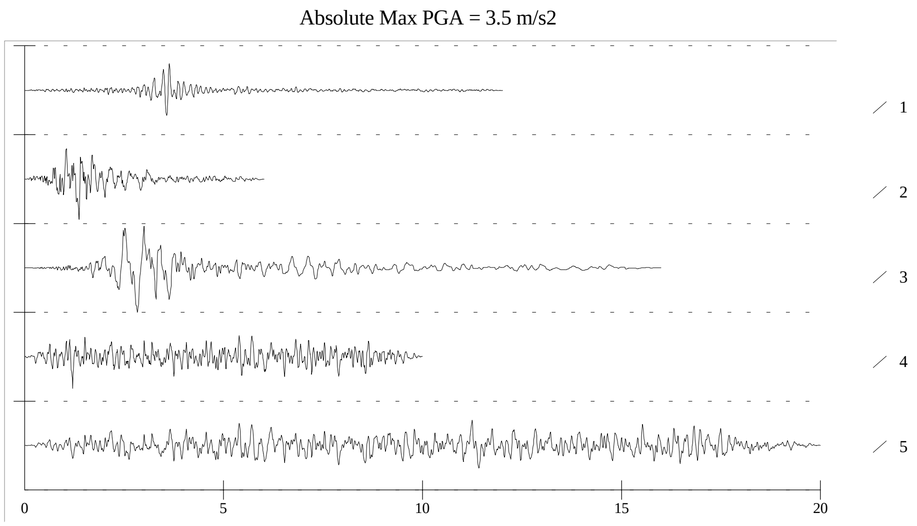

Figure 3 : Input accelerograms at outcropping bedrock

3. RESULTS

All calculations have been performed with CyberQuake with three different hypothesis on the soil behaviour: non-linear elastoplastic behaviour, equivalent-linear behaviour using G/D-γ curves simulated by elastoplastic constitutive model (named EP) and equivalent-linear behaviour using G/D-γ curves from the literature (named BB). Both soil columns of Table 2 are considered, just as the five bedrock accelerograms of Figure 3. Even if three-dimensional kinematics lies in CyberQuake, the input motion is applied only in one horizontal direction.

3.1. In terms of PGA

Figure 4 gives the variation of peak ground accelerations at soil surface relatively to peak accelerations at outcropping bedrock, for both soil profiles and three behaviour models. It is important to remain that each PGA on Figure 4 corresponds to time histories being very different in origin and shape. Juxtaposition of both artificial and real accelerograms on these curves reduces the possibilities of deriving general conclusions.

It appears that the peak acceleration is systematically much lower on profile n°1, because of the low resistance of the clayey silt between 11 and 18 meters depth, which increases the damping of this formation and deamplifies ground motions at high frequencies. Effects of elastoplastic model on the maximum accelerations is not clear, probably because the frequency content has been modified by non-linearity. For both columns, simulated peak ground accelerations are higher when using equivalent-linear model with standard G/D-γ curves than with specific G/D-γ curves.

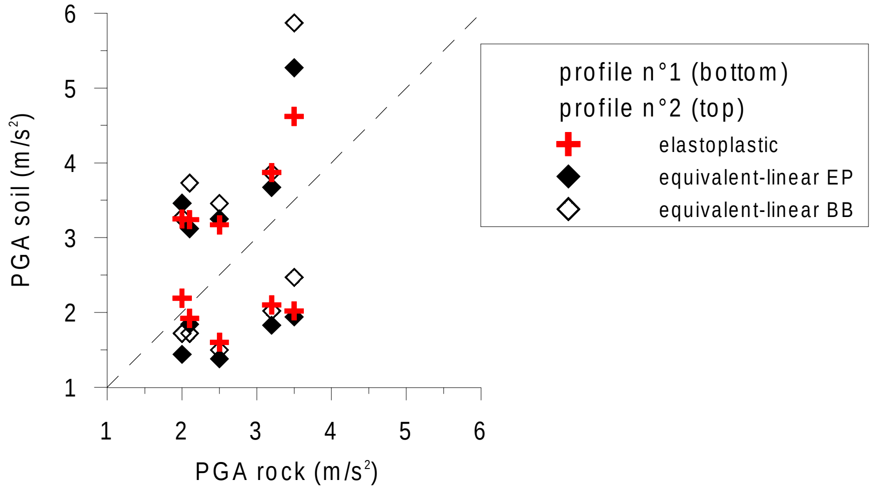

Figure 4 : Variations of simulated PGA at top of soil profiles versus input rock PGA

3.2. In terms of spectral content

Figure 5 presents the acceleration response spectra versus period obtained when submitting both soil profiles to the lowest input time history, which is the artificial accelerogram at 2.1 m/s^2. On the other hand, Figure 6 gives results for the highest input accelerations, which is the real accelerogram at 3.5 m/s^2.

For profile n°2, amplification of spectral acceleration is noticed in the whole period range smaller than 1 second. Amplitudes are particularly high around 0.3 s. Peak positions are slightly different when considering different hypothesis for soil behaviour : the fundamental period is around 0.3 s. for equivalent-linear model and 0.25 s. for elastoplastic model. This observation together with the fact that high frequencies are not filtered out by soils of column n°2, shows that soil behaviour is closest to linear than to non linear.

Simulated spectral ordinates are much lower for profile n°1. Ground motion deamplification appears under 0.5 s while acceleration are amplified at higher periods between 0.5 and 1.5 s. Distinct positions of peak can be noticed between elastoplastic and equivalent-linear results.

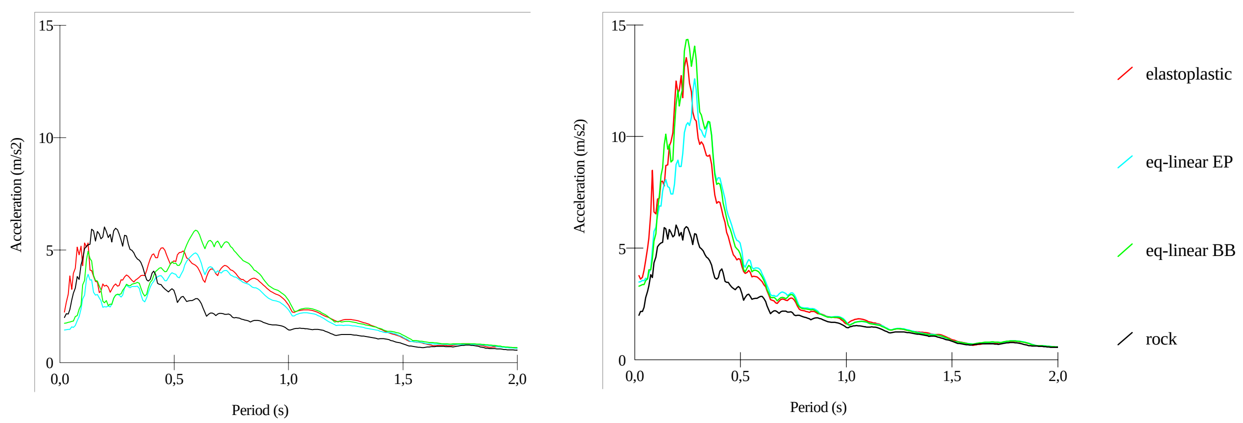

Figure 5 : Elastic response spectra simulated at top of profile n°1 (left) and n°2 (right) with artificial accelerogram n°5 as input rock motion

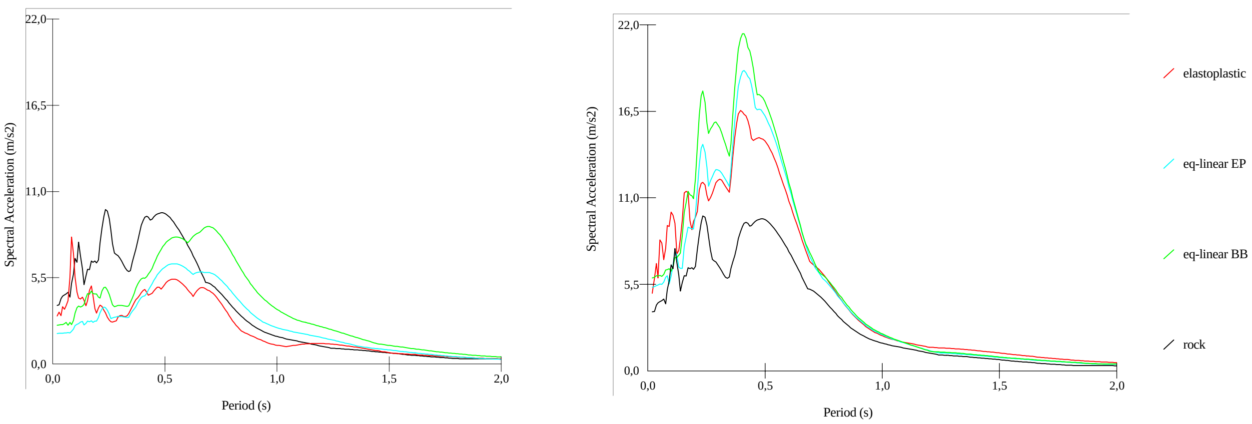

Figure 6 : Elastic response spectra simulated at top of profile n°1 (left) and n°2 (right) with real accelerogram n°3 as input rock motion

For higher loading levels such as an input motion with PGA of 3.5 m/s^2 (Figure 6), the use of an elastoplastic model shows that all frequencies greater than 1 Hz are more or less filtered out, which traduces slight non-linear effect. The amplification / deamplification features are less marked on real signals than synthetic ones, because the latter presents a great number of loading-unloading cycles at the same strain level.

These curves also illustrate that the response of equivalent-linear models using specific G/D-γ curves, i.e. simulated by elastoplastic constitutive model, most certainly better fits the real soil behaviour than standard G/D-γ curves picked up in the literature.

3.3. In terms of wave shape

Analysis is performed with real accelerogram n°2 as input rock motion. Figure 7 compares surface ground accelerations obtained with both hypothesis about soil behaviour : equivalent-linear and elastoplastic. It clearly appears that the main difference lies in the erasing of high frequency content in equivalent-linear analysis. This can be explained by the formulation of the iterative process, where damping values are determined from D-γ curves for an effective strain defined as a fraction of maximum strain. Therefore, the whole signal is affected by a damping corresponding to highest distortion peaks, and high frequencies tend to be filtered out.

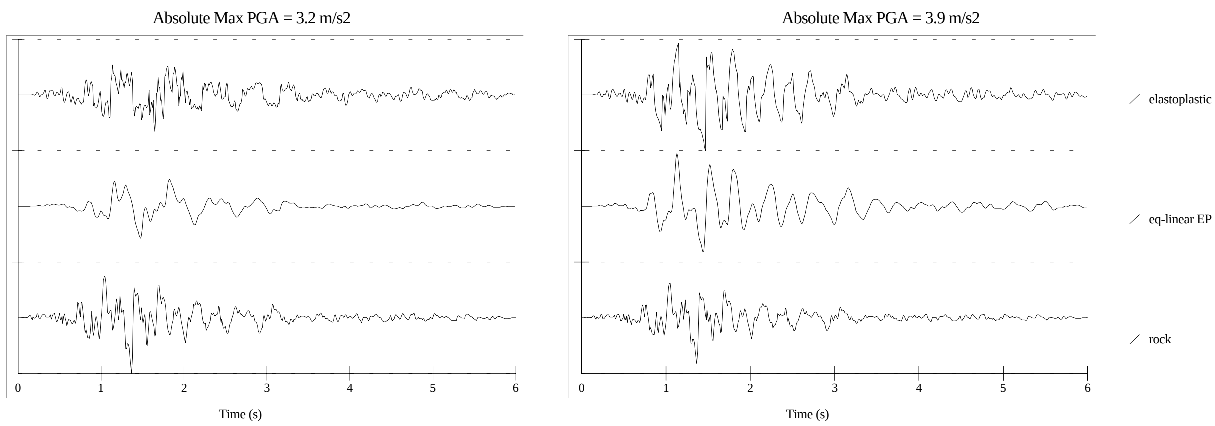

Figure 7 : Accelerograms simulated at top of profile n°1 (left) and n°2 (right) with real accelerogram n°2 as input rock motion

To identify the layer in which the modification occurred, we extracted computed time histories at each layer interface. Figure 8 presents the variation of accelerograms with depth in both soil profiles. Only results from elastoplastic simulations are showed. In soil column n°1, the ground motion is strongly modified in layer 4 constituted by clayey silt of poor resistance at 15 meters depth. The damping of this formation deamplifies the incident motion. On the other hand in profile n°2, the transformation occurs in above sandy layer, without any shift of peak acceleration and with significant amplification regarding to rock motion. This is also a way showing that a same layer can generate very different seismic response when submitted to different input motions.

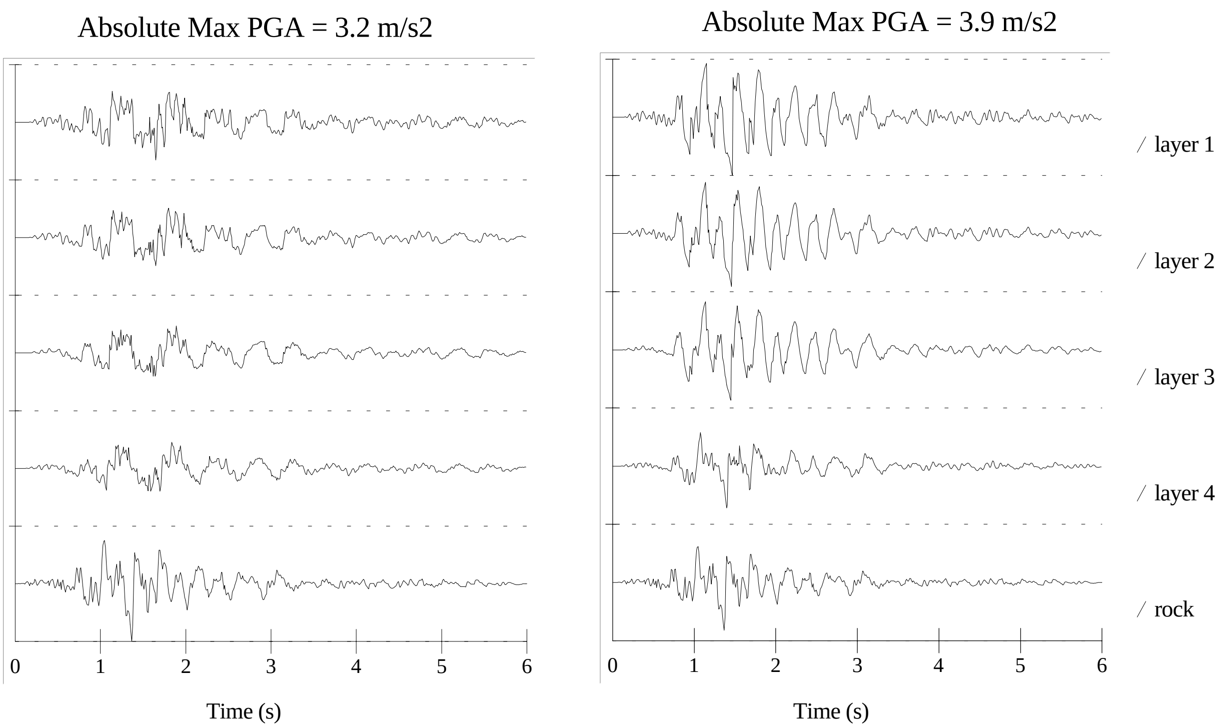

Figure 8 : Variation of simulated accelerograms from bottom to top of profile n°1 (left) and n°2 (right) with real accelerogram n°2 as input rock motion and elastoplastic soil behaviour

4. CONCLUSIONS

Results of numerical simulations show that a geological formation having poor mechanical characteristics and situated at depth significantly influences the seismic response obtained at the surface of multilayered sediments. Low resistance of the studied clay layer increases its damping, which attenuates the high frequency content and therefore the peak ground acceleration. Fundamental periods determined with a equivalent-linear or a non-linear assumption were not significantly different.

This comparative study constitutes the first step in a extended parametric analysis. These very preliminary results will be completed by further analysis using more diversified soil columns and input motions, in order to derive complete and detailed conclusions.

With this few examples, we have also shown that CyberQuake constitutes an efficient tool for determining the seismic response of surficial formations in the non-linear domain. The code is optimised for quick calculations and also includes equivalent-linear approach. The decrease of shear modulus and the increase of damping with distortion are suitably simulated and well adapted to mechanical characteristics of real materials. In equivalent-linear simulations, CyberQuake allows using these specific G/D-γ curves rather than standard G/D-γ curves picked up in the literature.

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