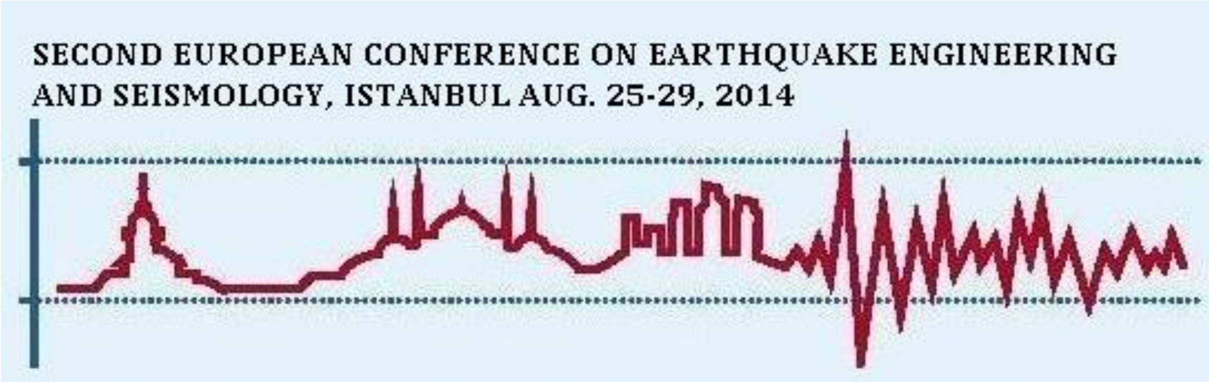

ESTIMATE OF THE TOTAL VOLUMETRIC STRAIN OF THE SOIL BY AMPLITUDE PARAMETERS OF STRONG-MOTION

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ABSTRACT

The total volumetric strain of soil seems to be an important soil damage criterion during earthquakes. Using the 150 strong motions database, empirical correlations are developed between amplitude strong motion parameters (peak ground acceleration, PGA, peak ground velocity, PGV and peak ground displacement, PGD) and between this parameters and the percentage of total volumetric strain. This work aims to highlight the parameter that best able to characterize an earthquake and the indicator that is the preferred for predicting damage in loose soil. The results of the correlations analysis between amplitudes parameters show that PGV is the parameter which best characterize the earthquakes than the others parameters and that PGA and PGV have a good linear dependence. Thus the correlations between the amplitude parameters and the volumetric strain of soil show that PGV is harmfulness indicator which best represents the damage in the loose soils during an earthquake. In addition, a prediction model of volumetric soil deformation is proposed and the performance of the predictive equation was checked according to the correlation coefficient R^2, variance (VAF) and the root mean square error (RMSE).

INTRODUCTION

Earthquakes have always presented a risk to the environment and the consequences of these earthquakes are appreciated during and at the end of the phenomena. These consequences are represented in terms of deformation, displacement, shear strain etc. The prediction of the risk is the most important topic in the field of earthquake engineering. Different strong motion parameters are presented in the literature over the past decades. They are often be used to represent different characteristics of seismic motion. The field observations and post-seismic and numerical investigations show the interdependence between the parameters of seismic motion and the state of damage of structures after earthquakes (Elenas. A (2000) and Elenas. A Meskouris. K (2001)). Strong movement parameters have always been considered essential and the key to characterize structural damages due to earthquakes (Alvanitopoulos et al, 2010) and they also present new criticalness parameters that provide information relevant to the indices of structures damages. The parameters used to characterize the amplitude of the strong movements are: Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV) and Peak Ground Displacement (PGD). They are also called

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maximum movement parameters (they are related to the energy released by the earthquake motion). They represent a subset of a broader set of parameters that characterize the strong movement (Kramer, 1996). According to Gandomi et al. (2011) these parameters have a critical role in explaining the characteristics of seismic motion.

The past few years, many studies have been performed to analyze the seismic records. Strasser and Bommer (2009) evaluated a set of data records of earthquakes high values of PGA (PGA> 1g) or PGV (PGV> 100 cm/s) and untapped, they tried to classify the causative physical processes in a uniform nomenclature. Douglas (2003) examined the attenuation equation and showed that there have been little argument revenue in the past 30 years have studied the relationship estimating the movement of soils. Baruah et al. (2011) have provided empirical relations between the parameters of movement depending on the magnitude of the earthquake, the type of fault, the depth of the source and the speed of characterization of the medium and the distance. Seismic motion parameters have been used to study the effects of the frequency of seismic loading on underground structures (Hamid Reza Nejat et al 2012) the results of this analysis show that the incident load frequency and natural frequency of a system have influence on the wave attenuation and dynamic damping of the system. Pineda-Porra.O and Ordaz. M. (2007) have used PGA and PGV to propose a new intensity parameters for estimating damages in underground pipelines caused by the propagation of seismic waves. In addition, the correlations analysis according to Elenas A (2000) and Elenas Meskouris A and K (2001) have presented characterization studies of classical parameters of accelerograms and have examined the degree of interdependence between them and the structural damage.

This work provided a method to quantify the relationship between the amplitude parameters of seismic motion and damages in loose soil. First, an accelerometrics data basis of 150 recordings (recorded in rocks and in depths) is processed and the amplitude seismic motion parameters considered are calculated for each record. Subsequently, to calculate the soil damage taking into account the nonlinear behaviour of the ground a dynamic modelling, computer assisted, is carried out for all recording previously treated. Total volumetric strain of the soil (ε_v) is selected as a criterion to representing soil damage during an earthquake. Finally, a correlation coefficient (R^2) is estimated to express the degree of dependence between parameters of seismic movement and between these parameters and the response of soil. According to the results of correlation coefficients a statistical prediction model is proposed and according to the following two indices values, variance (VAF) and root mean square error (RMSE), the performance of the proposed statistical model is controlled.

DATABASE

In this study were used a dataset of 150 seismic records, registered in depths and in rocks for the different events. These seismic records are provided by the United States Geological Survey "Strong-motion database" downloaded from the web-site of the USGS. The description of the database is represented respectively by the histogram appeared in Figure 1 which shows the distribution of all events considered in this study in function of the magnitudes of moment magnitude Mw between 4 and 6.7 and the point cloud shown in the figure 2, illustrates the distribution of acceleration in the event considered appropriate depending on the epicentral distance 0 <D (m) <156.

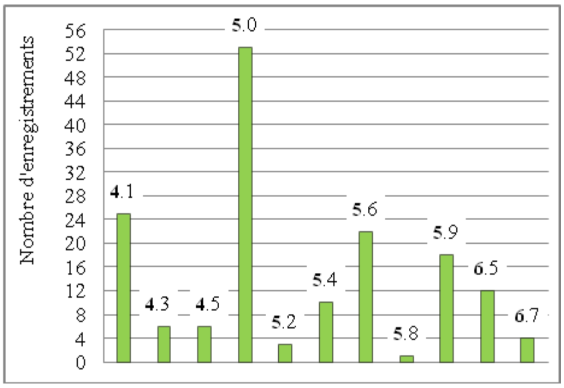


Figure1. Distribution of seismic records considered in relation to the seismic event

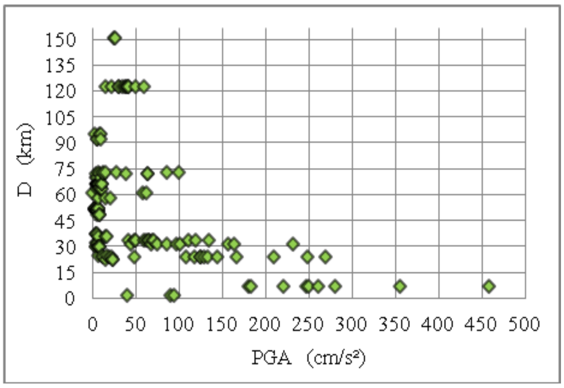


Figure2. Earthquake epicentral distance D Vs PGA

SOIL PROFILE AND DYNAMIC MODELLING

To determine the percent of the volumetric deformation of the ground, under the action of 150 seismic records, a non-linear dynamic modelling is carried out. The choice of the soil profile is based on the susceptibility of the latter to breaking and the possibility to amplify seismic shaking. The considered profile has a shear velocity (Vs30) of 215 m / sec; according to the classification of the Algerian Earthquake Regulation (RPA 99/03) is a ground-type loose. The numerical simulation tool is the finite element code Plaxis 2D (version 2011). This software requires the utilization of the conditions set limits and the standard absorbent boundaries were used to avoid the reflection of seismic waves. The mesh size used is the triangular type refine at 15 knots.

To take into account the nonlinear behaviour of the soil, the Hardening Soil Small model is selected to provide a dynamic simulation close to real soil behaviour. However, the HS-Small model requires eight major parameters identifiable from the Triaxial and odometer test. The set of parameters used is summarized in Table 1.

Table1. Paramètres utilisés lors de la modélisation avec le modèle HS Small

E_{50}^{ref} (Mp)	46.12	γ_{unsat} (Kn/m3)	11.30
E_{eod}^{ref} (Mp)	25.50	$\gamma_{0.7}$	0. 2 e-4
E_{ur}^{ref} (Mp)	101.7	ν_{ur}	0.2
C (Mpa)	1	R_f	0.9

The obtained results from the soil response modelling are in terms of the total volumetric deformation of the soil (ε_v) which is a criterion of damage in the ground during an earthquake. Figures 3 illustrate the distribution of damage in the soil depending on the moment magnitude (Mw) and epicentral distance (D). However, it is observed that the total volumetric strain of the soil increased with the magnitude, more than Mw is greater, ε_v is important. By against, it is observed that epicentral distance does not have a direct impact on the total volumetric strain of the soil. Because, sometimes, earthquakes are recorded at over 100 Km, to the earthquake source, but give a significant percentage of deformation. So, the moment magnitude of an earthquake, that is the response of soft soil, plays a role in degradation and notes that the value of the epicentral distance only does not affect soil degradation.

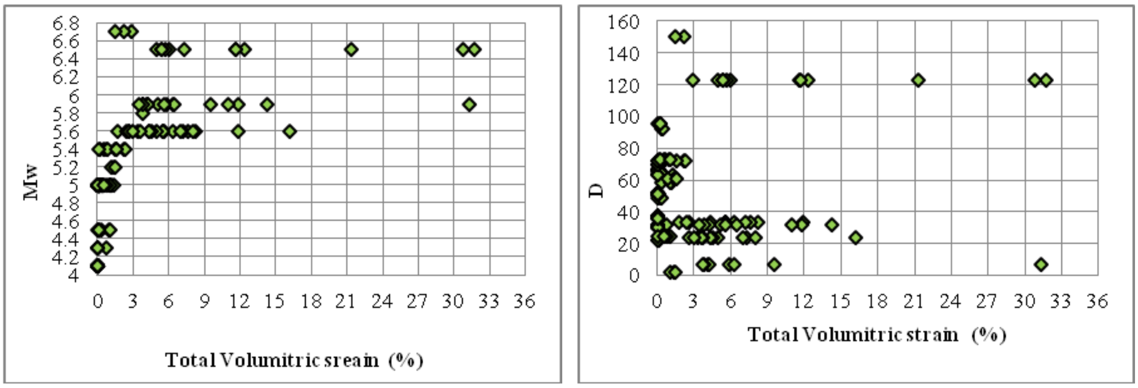


Figure 3. Response of soil in terms of total volumetric strain of soil in function of moment magnitude (Mw) and epicentral distance (D).

CORRELATION BETWEEN TOTAL VOLUMETRIC DEFORMATION OF SOIL AND GROUND MOTION AMPLITUDE PARAMETERS

AMPLITUDE PARAMETERS OF STRONG GROUND MOTION

The amplitude of an earthquake can be described by parameters which are calculated directly from the seismic record, such as by the parameters which are calculated indirectly; parameters considered in this study are the peak ground acceleration (PGA) the peak ground velocity (PGV) and the peak ground displacement (PGD). The choice of these parameters dates back on the one hand to the available literature reviews which have shown the lack of studies based on the velocity that the studies based on the acceleration, although the terms are slightly accelerating damage to structures under seismic excitation (Benamra.T et al 2013). On the other hand, the choice of PGV is relative to the report between this parameter and the deformation. Newmark [1967] has proposed that the maximum deformation of the ground in an arbitrary direction can be estimated by using the relationship between PGV and the propagation velocity of seismic wave and PGA. In addition, Yakut and Yilmaz [2007] emerge on conclusion, after presenting a series of analysis of systems in multi degree of freedom, that PGA is the best indicator of damage than PGV. Moreover, the peak ground acceleration is the most used for the design of structures to the present day setting, although it is a measure that is limited at high frequencies and has very little correlation with structural damage however, is widely used because of its simplicity. Regarding the maximum ground displacement, according to Maniyar MM and RK Khare (2011) PGD is the parameter less commonly used to characterize the ground motion and this is because of the difficulty of determining precisely as a result of accumulation of errors when filtering and integration of accelerogram. To estimate PGD in terms of damage the only solution is to find a way to connect PGD with PGA or PGV, like Mexico City maps are available [Pineda and Ordaz, 2004, PGV, [Pineda 2002] for PGA]. These three parameters considered are calculated for each record and a correlation study is performed to determine the dependency between them and see that it is the most essential of them that best characterizes the energy of the ground motion. These parameters were used to predict damage due to earthquakes, Waldet al. (1999) developed a regression relationship between the Modified Mercalli Intensity (MMI) and PGA or PGV in order to generate intensity maps that give a quick view on the extent anticipated damages and can be used for interventions of emergency a few minutes of the event. The maximum ground velocity (PGV) is regularly cited as one of the most appropriate parameters to account for the destructive power of seismic movement (Liu and Zhang, 1984). Indeed, all easily calculable that the PGA, PGV appears more appropriate because the destroyer character of an earthquake is related to the energy flux transmitted to the structure, itself characterized by the velocity (Mohammadioun and Mohammadioun, 2004), the PGV is mainly used for the elaboration of shake map, together with the PGA (Cua et al, 2010). Several authors have emphasized that each of these three peak amplitude parameters can be considered as representative of a range of specific intensity (Chernov and Sokolov, 1983; Aptikaev and Shebalin 1988; Chernov, 1989. Wald et al, 1999) and (Sokolov, 2002), acceleration is considered by these authors as being representative of low intensity, speed moderate intensities, and the displacement of large currents.

CORRELATION ANALYSIS

After have performing a nonlinear dynamic modelling for each seismic recording to the loose soil profile chosen, the total volumetric strain of the soil is correlated with the amplitude parameters of soil, previously considered, through the coefficient correlation of determination (R^2). The values of R^2 have been based on the linear regression lines and the form of the relationship is taken as y = ax + b. Where a and b are constant coefficients.

Table 2 presents the correlation between the amplitude parameters and the correlation between them and the response of the soil in terms of the total volumetric deformation of soil. The results concerning the correlations between the parameters clearly show (i) how all three amplitude parameters are relatively independent, in other words, good correlations are given between parameters that are obtained by a derivative or a single integration and between the parameters that are obtained by double integration or bypass (ii) all the considered parameters have good correlation with PGV (correlation coefficient R ² greater than 0.55). Therefore, PGV seems a good compromise between the three amplitude parameters (iii) PGA alone does not always give accurate information on the damage earthquake potential, but it represents good dependence with PGV and this dependence can assign a simple linear formulation to calculate PGV in terms of PGA (Figure 4).

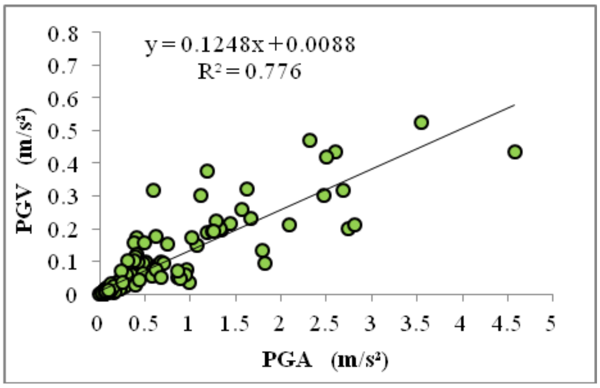
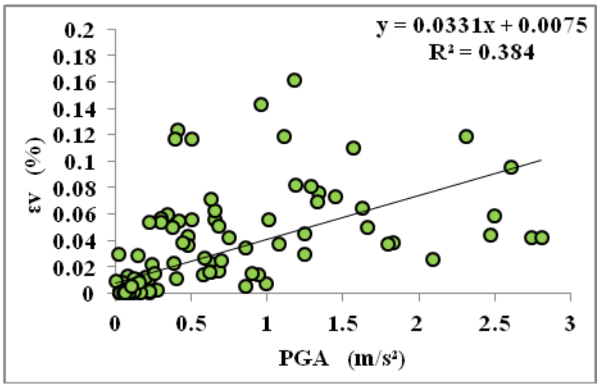


Figure 4. Visual result of the PGV-PGA correlation analysis

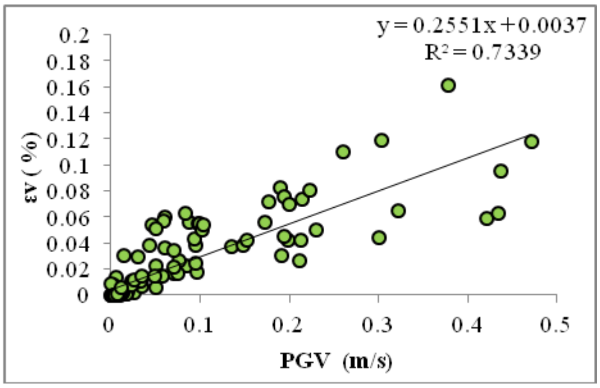
Furthermore, Table 2 shows the correlation coefficients (R ²) of correlation analysis performed between amplitude parameters and the total volumetric strain. Figure 5 (a), (b) and (c) represent the scatter plots and the straits regression line between amplitude parameters of motions and soil response. Thus, the equation of the tendency line obtained between for each pair. The best dependency is between ε_v and PGV with an R ² of 0.734 (Figure 5 (b)). Therefore, PGV is the parameter that gives the best description of damage in the ground falling on an earthquake; therefore the volumetric strain of the soil is influenced by this parameter and not by PGA and PGD.

Table 2. Correlation coefficients for the different parameters

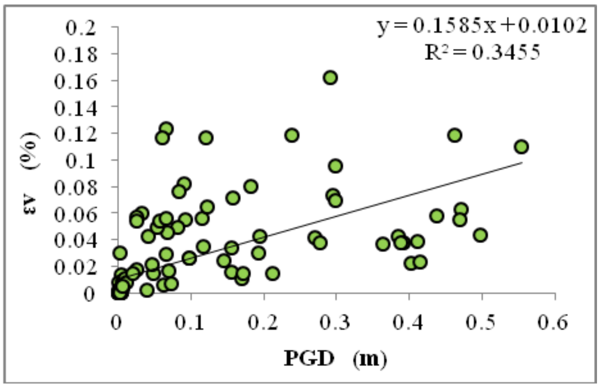
paramètres	**PGA**	**PGV**	**PGD**	**ε_v**
PGA	1	0.776	0.496	0.384
PGV	0.776	1	0.552	0.734
PGD	0.496	0.552	1	0.345
ε_v	0.384	0.734	0.345	1



(a)



(b)



(c)

Figure 5. Correlations between the soil response and amplitude parameters of seismic motion

Consequently, strong ground velocity is a good indicator of harmfulness and it has impact damage on loose soil, this indicator is used to provide a prediction formula. This formula intended to predict total volumetric strain of soil during an earthquake and estimate the maximum velocity of an earthquake that causes more damage to the soil. The following equation (1) has been revealed by the regression analysis between ε_v and PGV.

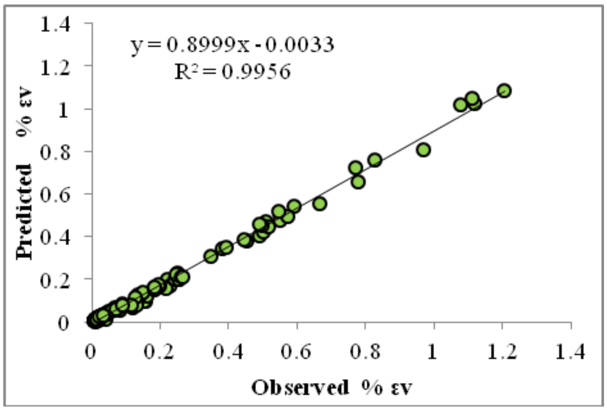
$$\varepsilon_v = 0.2551 PGV + 0.0037 \qquad (1)$$

In order to demonstrate the relationship measured and predicted values, the percentage of the total volumetric deformation measured is compared with the predicted values established from the nonlinear modelling of the ground, as shown in Figure 6. In fact, the correlation coefficient between measured and predicted values is a good indicator to verify the performance of the prediction model. (Gokceoglu and Zorlu, 2004). The VAF and RMSE (equation 2, 3) are two indices used in this study to control the performance of the predictive ability of the predictive model developed as was used by Alvarez Grima and Babuska (1999) Finol et al. (2001), Gokceoglu (2002) and Yelmaze Işık (2006).

$$VAF = [1 - \frac{\mathrm{var}(y - y')}{\mathrm{var}(y)}] \qquad (2)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y - y')^2} \qquad (3)$$

Where, y and y 'are respectively the predicted and measured values. If VAF is 100% and RMSE is 0, then the model is excelling. The indices show that the proposed model has a good performance for damage of soft ground prediction during an earthquake, according to the index values VAF and RMSE, 93.0259% and 0.2054 respectively. The calculated indices are given in Table 3. The obtained indices show that the prediction model established is very powerful. Accordingly, the use of this formula is assigned to the practice of design for the prediction of damage in soft grounds relative to a possible earthquake with a maximum speed PGV known.



(c)

Figure6. Cross correlation between the predicted and measured values of the percentage of volume deformation of soft ground,

Tableau 3. Indice de performance (VAF, RMSE et R²)

Modèle	***VAF (%)***	***RMSE***	***R²***
Régression model	*93.0259*	*0.2054*	*0.995*

CONCLUSIONS

Nonlinear dynamics modelling is the basis of construction of this correlation study. The modelling results show that the volumetric soil strain is influenced by the magnitude of the earthquake and not by the epicentral distance. Analyzes of correlations for amplitude parameters are developed using 150 seismic records and correlation analyzes between amplitude parameters and percentage of the total volumetric strain are performed. It is observed that the correlations between amplitude parameters show a good correlation of the PGV with PGA and PGD. It is showed that PGV is a good compromise between the three amplitude parameters and it is the best parameter that characterizes the seismic movement of a loose soil. As regards, results of the correlation analysis between the amplitude parameters and the soil response, the PGV presents the better correlation with the percentage of total volumetric strain. So, PGV is the parameter which best represents the nonlinear soil behaviour between the three considered in this study.

To estimate soil damage, a predictive model has been proposed for predict the volumetric strain during an earthquake. The performance of this suggested equation was controlled by the coefficient of correlation (R^2), the indices of statistic control "VAF" and "RMSE". However, the control of performance of the prediction model indicates that the proposed formulation in this study seems to be accurate in estimating the damage of the soil due to PGV. Therefore, it is more compatible to used this result (use of PGV) to schematize the spectrum of design and using it to develop a correct seismic input in the calculating dynamic of structures (record which takes into consideration the soil deformation and soil behaviour) because the selection and the scaling of earthquake movements is a very important step in defining the seismic loads that will be applied to a structure in a structural analysis and serves as an interface between cosmology and engineering.

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