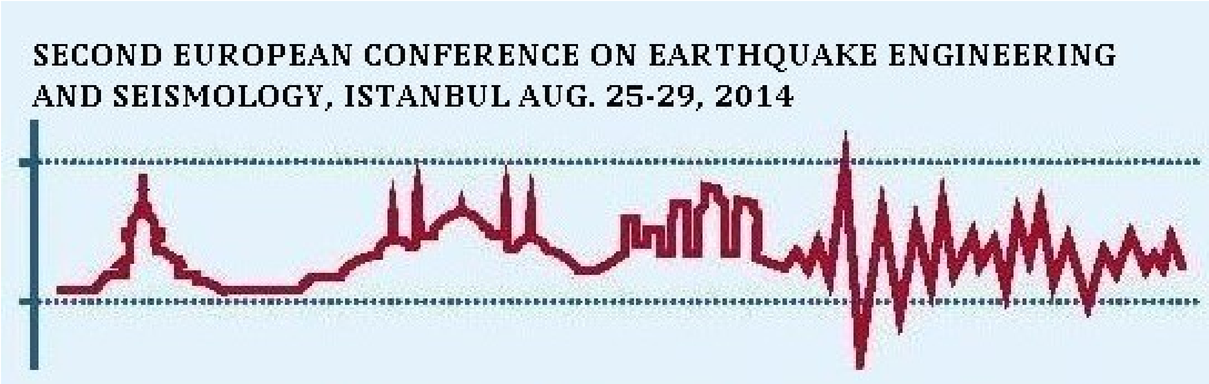

NUMERICAL EVALUATION OF SLOPE TOPOGRAPHY EFFECTS ON SEISMIC GROUND RESPONSE AND CORRELATION WITH OBSERVED DAMAGES IN CORSO CITY (ALGERIA) AFTER MAY 2003 EARTHQUAKE

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ABSTRACT

This work is a parametric evaluation of seismic ground response associated with the slope topography effects. The analysis is carried out by the universal program 'FLUSH' which uses the 2D finite elements to calculate the ground column response at free field and the responses at any point of the medium. We first investigate the influence of some key parameters (slope angle, frequency content of incident wave, soil profile,...) to better understanding the slope topography effects in term of amplification/deamplification of responses.

In general the responses are amplified at the upper surface of slopes and attenuated at their base. This variation is affected by the slope angle, the stiffer slope accentuate the effects. At the upper surface, the horizontal movement becomes complicated in the sense that it varies significantly along small distance from the crest. This variability generates differential movements likely to cause damage to structures. Also, the topographic effects are influenced by the ratio between the slope and global heights, which can translated to the one between the ground natural frequency and the topographic frequency. For comparable frequency values, the seismic motion at the crest is more amplified.

During the 2003 Boumerdes earthquake, the “cité des 102 logements” built on hilltop, in Corso, some four story RC building collapsed while others experienced severe structural damage and the rest experienced only slight damage. The distribution of damage is related to the distance from the crest. In this study, a numerical evaluation of seismic ground motions of the site (the slope with its lower and upper surfaces) is done and the results led us to the conclusion that topographic effects may be involved in increasing the damage level in the of buildings.

INTRODUCTION

Observations during earthquakes showed that at a given site, the records at distinct points are different. The surface topography is one of the important influential factors of this variation and it has been recognized that the destructiveness of ground shaking during earthquakes is affected significantly by topographic amplification. The presence of a strong topographic relief (hill, ridge, canyon, or slope) has an effect on ground shaking in term of amplitude and frequency content. Also, post destructive earthquake investigations indicate that buildings located at the tops of hills, ridges and canyons, suffer more intensive damage than those located at the base.

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Example of these observations are cited in Boore (1972) (San Fernando Earthquake, 1971), Celebi (1987) (Chile Earthquake, 1985), Kawase and Aki (1990) (Whittier Narrows Earthquake, 1987) and Restrepo and Cowan (2000) (Armenia Earthquake, 1998). The recent earthquake of Boumerdes in Algeria 2003 (Laouami et al. (2003)) brought additional evidence of severe damage of structures built on hilltops (Corso city).

One of the first studies to specifically consider the seismic response of soil slopes was conducted by Idriss and Seed (1967) who were encouraged by the extensive landslides generated during earthquakes. They conducted a parametric study of the response of 27°clay slopes, and later of 45° slopes. They observed that the peak surface acceleration was in all cases greater at the crest of the slope than at points lower on the slopes. Vertical motions caused by the horizontal component of the base motion were generated near the crest of the slope.

Kovacs et al (1971) performed laboratory shaking table experiment on clay banks, they concluded that the thickness of the soil deposit was the predominant factor in determining the site response.

Sitar and Clough (1983) used an equivalent linear, two-dimensional finite-element model to show that the motion were amplified up to 70% at the crest of the slope compared to the free field behind the crest but they noted that these topographic effects tended to be small relatively to the amplification that occurs in the free field due to the site period.

Ashford et al. (2007) explored a complete range of slope angles between 30° and 90°, using the numerical model in which the geometry and geology of the configuration are simulated, developed by Deng (1991). They analyze a stepped half space which is a simplification of the problem of a steep slope in a uniform viscoelastic material. They illustrate the significance of steep slopes on site amplification and determined the peak topographic aggravation for the free field response of a homogeneous half-space. The amplification at the crest implies that the relationship between the slope height and the shear wave velocity of the soil behind the slope is very important in quantifying the effect of topography. They also evaluate the relationship between the natural frequency of the site and topographic amplification, the results indicate two important points: the natural frequency of the site has a greater effect on surface amplification than does the topography for high levels of impedance ratio and it appears that the topographic amplification can be added onto the amplification caused by the natural frequency. The topographic effects are more significant for wavelength comparable to the irregularity geometry, and considered negligible for low frequencies (Aki (1988), Ashford (1997))

This work presents first a parametric study of the slope effects on seismic ground response. The analysis is done by the FLUSH program which is based on 2D finite elements and easy to model complicated surface configurations and soil stratification. The objective of this investigation is to investigate the role of certain key-parameters such as slope angle, frequency content of the signal at the base and the effect of the soil profile to better understanding the slope topography effects in term of variable amplification/deamplification of responses at short distances, generation of differential movements and vertical components.

Also, a numerical evaluation of seismic ground motions of the "cité des 102 logements" site, built on hilltop, in Corso city, using accelerations recorded during the 2003 Boumerdes earthquake is done. The results led us to conclude that topographic effects may be involved in increasing the damage level of building. The distribution of damage is related to the distance from the crest and the results are well correlated with this distribution.

EFFECTS OF SLOPE ANGLE

The model in figure 1 is used in the analysis; it consists in homogeneous layer overlying bedrock with shear wave velocity of 1200m/s. The soil is truncated for an artificial boundary which will transmit all the waves out of the finite model. Viscous boundaries along the plane surface were used to include the soil 3D aspects. The seismic motion is generated by SH wave type, vertically propagating.

We consider the topographic characteristic H which is the height of the slope, λ denotes the predominant wave length of the SH waves and V_s shear wave velocity. The ratio of the characteristic dimension of the slope H and the wavelength λ defines the dimensionless frequency of incident waves.

In order to analyze the effects of slope angle (S), an isotropic, homogeneous and linear elastic soil layer with uniform properties of height $H = 20m$, shear wave velocity of 200m/s is considered. The results in term of acceleration are presented in figures 2 to3. All the responses (Horizontal and vertical accelerations) are normalized to the horizontal response at free surface (free surface of a soil column far from the slope (point A)).

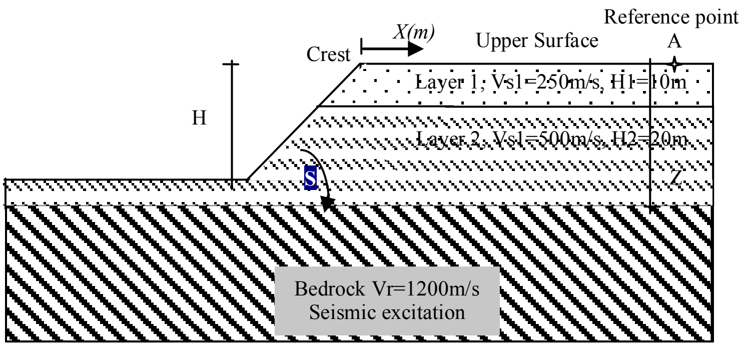

Figure 1. Configuration of the slope

At upper surface (figure 2), the horizontal movement becomes complicated in the sense that it varies significantly along small distance from the crest especially in the case of stiffer slopes (75°, 60° and 45°). Consequently, on the entire neighboring upper horizontal surface, the differential motion appears likely to cause damage to structures. Vertical movements are generated, their amplitude increases with the slope angle. These generated vertical movements are important up to 20m from the crest and become negligible further.

These results compared to what seismic codes provisions prescribe, provide useful conclusions for more precisions and practical details concerning the topographic effects phenomena. Specifically, the range of amplification found is comparable to the provisions of the European EC-8 which do not specify the distance from the crest 'near the top edges'. However, the horizontal peak acceleration may be amplified far from the crest even for weak slope. Furthermore, EC-8 totally ignore the generation of a parasitic vertical motion. Moreover, it completely overlook the spatial variability aspect of the horizontal motion at the upper surface (differential motion is induced) especially for steep slope

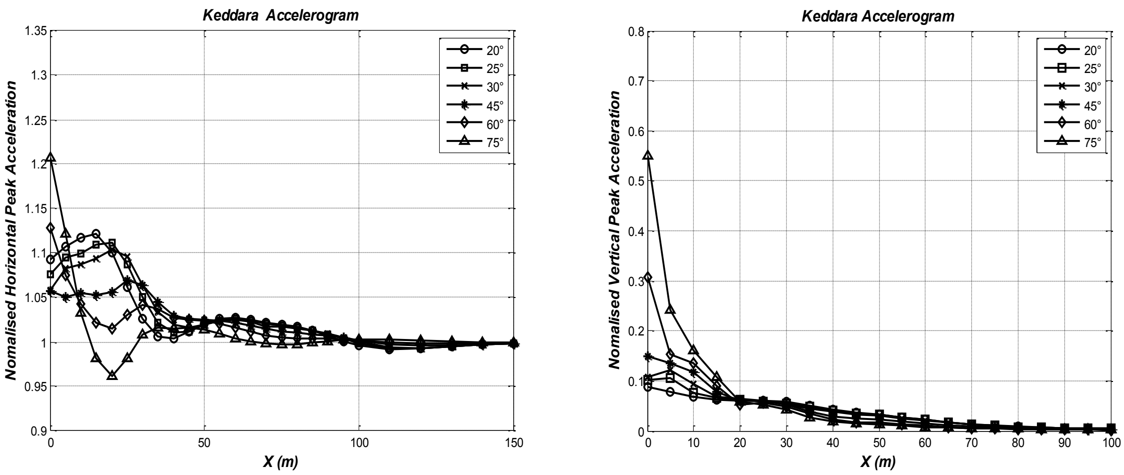

Figure 2. Effect of slope angle on normalized horizontal (left) and vertical (right) peak acceleration

EFFECTS OF DIMENSIONLESS FREQUENCY OF INCIDENT WAVE

The present paper suggested analyzes based on parametric studies that include the dominant frequency of the Keddara excitation and the average shear wave velocity of the profile to acquire relation between adimensional frequency H/λ and topographic effects. The slope height H is fixe and equal to 20m, while λ refer to wave lengths given by $\lambda = V_S.f$.

V_S. is the mean shear wave velocity of the soil profile, and f is the dominant frequency of the input motion at the bedrock.

First the effect of dimensionless frequency of incident wave H/λ on the seismic response of the upper surface is investigated. Results of the analyses for a 45° slope with four values of averaged V_S (100, 200, 500, and 800m/s) are presented in figure 3. From the results, it is clear that the acceleration tends to one of free field for shear waves velocity of 800m/s (Stiff soil) and the vertical acceleration negligible. This is due to the higher value of wave length λ compared to the slope height H .

For lower values of V_S (100 and 200m/s), we observe an amplification-deamplification in the horizontal response. It is very important near the crest, 27%. The peak acceleration tends to the free field response for distances from the crest greater than 20m. An important vertical peak acceleration is induced but attenuate quickly especially in in case of stiffer soils ($V_S > 500m/s$) to become nil for distance greater than 10m.

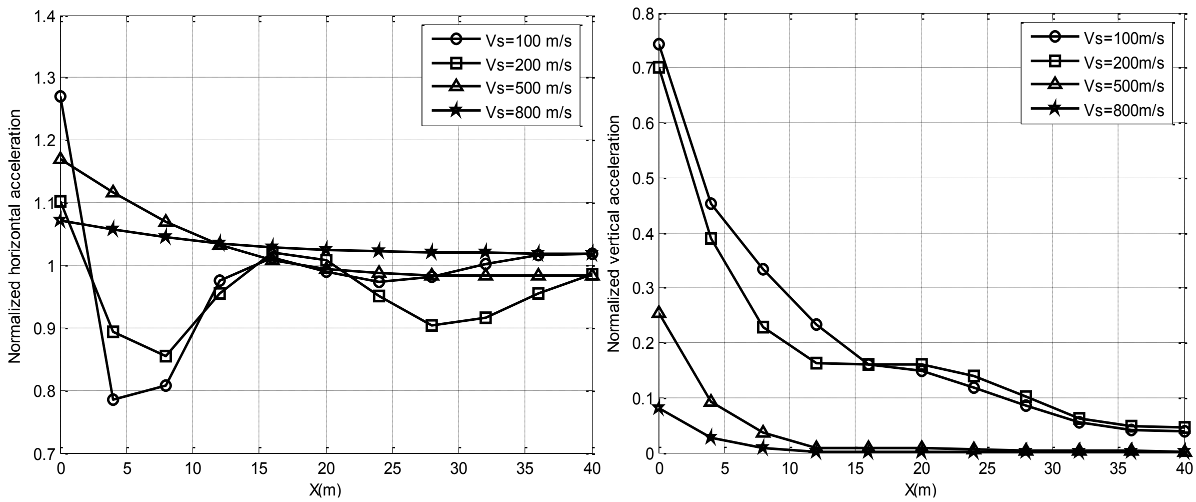

Figure 3. Effect of profile type on normalized horizontal peak acceleration (left) and vertical peak acceleration (right)

To better estimation of topographic amplification, we investigate the Topographic Aggravation Factor 'TAF' (Assimaki (2004), Bouckovalas et al (2005), Nguyen et al. (2007)) which is defined as the ratio of the Fourier amplitude spectrum of the horizontal acceleration at the crest to the free field motion.

The variation of the TAF according to the adimensional frequency H/λ is given in figure 4 for Keddara acceleration. The results show largest amplification in the neighbour of the adimensional topographic frequency H/λ=0.25 which correspond approximately to the fundamental frequency of the column behind the crest, and still be important between 0.15<H/λ<035.

This result is well consistent and interesting, since it takes into account soil stratigraphy, soil bedrock interface and real excitation. It is important to mention that the Keddara excitation is considered as near field excitation (rich in high frequencies), this can explain in a part the important observed topographic amplification.

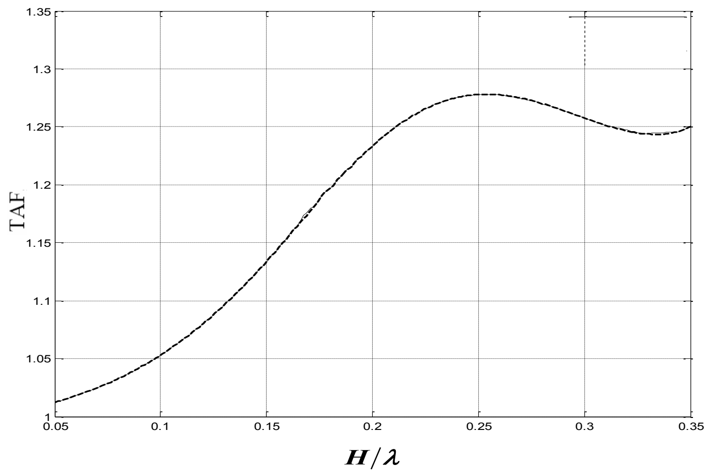

Figure 3. Topographic aggravation factor computed at crest ($x=0$) for Keddara accelerogram

CORRELATION WITH OBSERVED DAMAGES IN THE SITE OF CORSO

During the 2003 Boumerdes earthquake (Mw = 6.8), in the “Cité des 102 Logements” situated in Corso town, about 2 km west of Boumerdes, one four-story building totally collapsed while a second experienced severe structural damage, the rest, particularly the three-story buildings experienced only slight damage (Bensalem et al. (2010)).

The ‘Cité des 102 Logements’ is located on a plateau bordered by a slope (around 21°, i.e., 38%) with a 25-m height variation. Bensalem et al. (2010) suspect that damages were linked to topographic effects rather than to geological site effects and confirm this this hypothesis from ambient vibration recordings performed over the Cité des 102 Logements and its immediate surroundings.

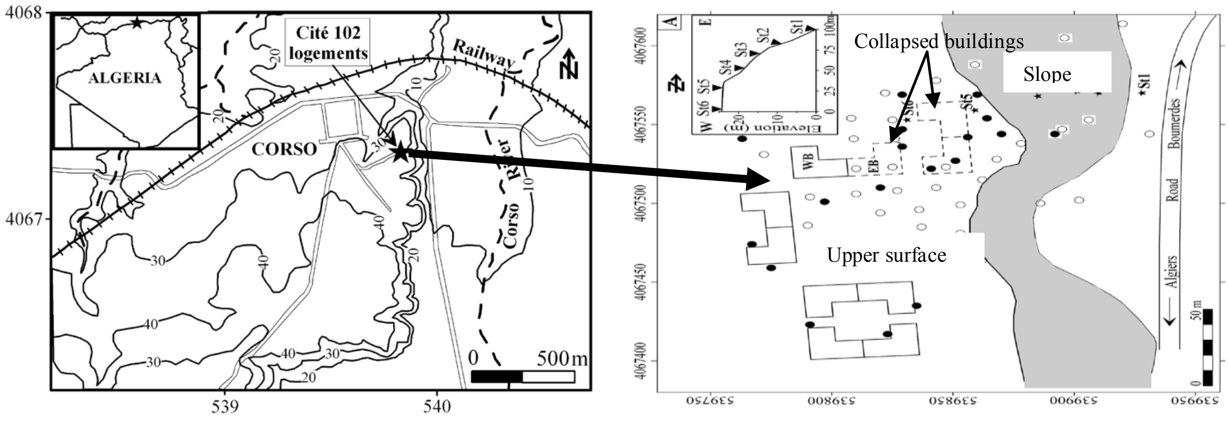

Figure 4. Map showing the “Cité des 102 Logements” location and details of the site (Bensalem et al. (2010))

In this part of study, the seismic profile of the site is the one of Bensalem et al. (2010). The results are first presented in term of transfer function between the lower surface and the upper surface which include both topographic effects and 1D effect (wave propagation effect). The transfer functions are presented in the figure 5. At the crest the maximal amplification is 1.96 and it increases with the distance from the crest to reach 2.2 at 24m.

These results are in good agreement with Bensalem et al (2010). The fundamental frequency of the site is about 3.75 Hz which is different than the ones of buildings. That let us to eliminate the resonance effect from the causes of damages and focus attention on topographic effect especially because of the concentration of damages on distance from the crest comparable with the ones influenced by amplification of horizontal acceleration, influence of generated vertical components and differential excitation as demonstrated above.

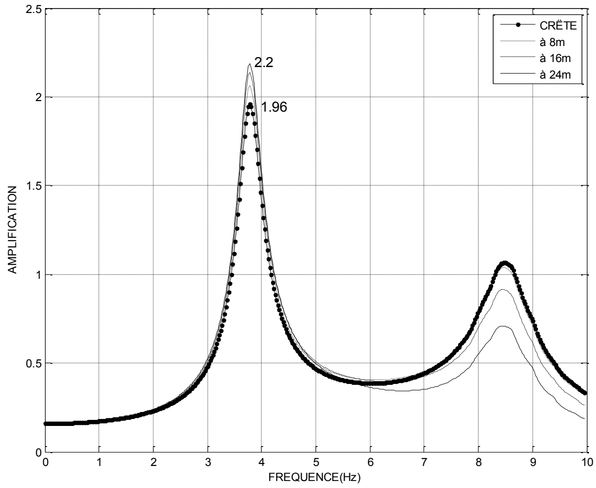

Figure 5. Transfer functions between lower surface and upper surface.

In a second analysis, the results are presented in figure 6 in term of ratio of Fourier amplitudes of response at free field and the responses in different positions at upper surface. The results show that the topographic amplification is maximal 8m far from the crest and decrease for lengthy distances. The distribution of the amplification is in good agreement with the position of damaged buildings and with the degree of damages.

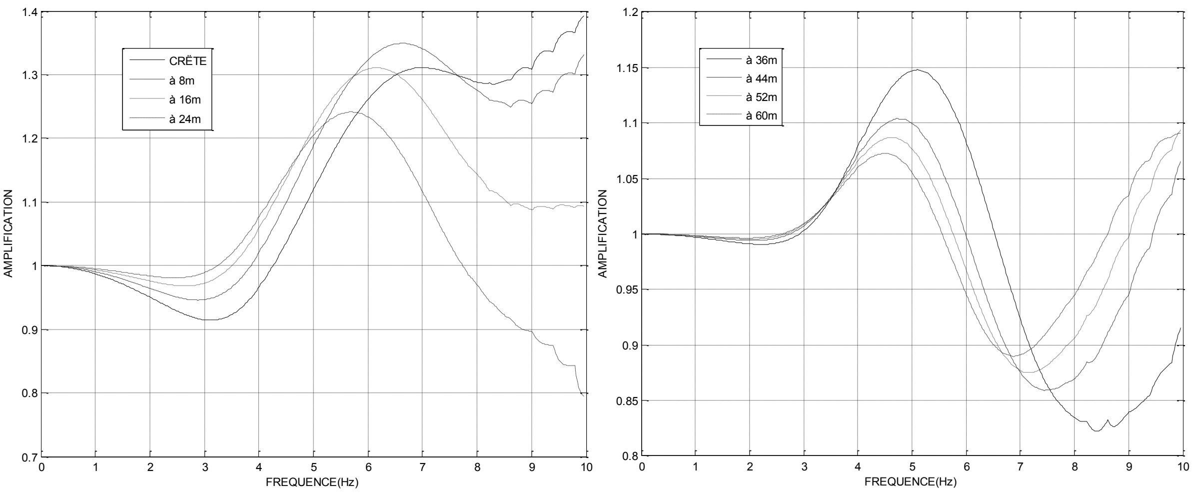

Figure 6. Transfer functions free field/upper surface

CONCLUSION

The parametric evaluation of seismic ground response associated with the slope topography effects is conducted in this paper. We first investigate the influence of some key parameters such as slope angle, frequency content of incident wave and soil profile model.

The horizontal responses in term of peak acceleration on the upper surface is complicated in the sense that it varies significantly along small distance from the crest especially in the case of stiffer slopes. Consequently, differential motion appears important. Vertical movements are generated and increase with the slope angle.

The effect of dimensionless frequency of incident wave on the seismic response is investigated. Results indicate that the acceleration tends to one of free field for very stiff models of soil (Vs around 800m/s) and the vertical acceleration negligible.

For soft models (V_S=100-200m/s), an amplification-deamplification is observed in the horizontal response, more important near the crest. To better estimation of topographic amplification, the Topographic Aggravation Factor 'TAF' is calculated for Keddara record. The results show largest amplification largely around the adimensional topographic frequency corresponding to the fundamental frequency of the column behind the crest. The Keddara excitation is chosen because it is rich in high frequencies (near field excitation), this explain in a part the important observed topographic amplification.

During the 2003 Boumerdes earthquake, the “cité des 102 logements” built on hilltop, in Corso, some four story RC building collapsed while others experienced severe structural damage and the rest experienced only slight damage. The distribution of damage is related to the distance from the crest. In this study, a numerical evaluation of seismic ground motions of the site is done. The ratio of Fourier amplitudes of response at free field and the responses in different positions at upper surface were calculated. The results show that the topographic amplification is maximal short distance far from the crest and decrease for lengthy distances. The distribution of the amplification is in good agreement with the position of damaged buildings and with the degree of damages.

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