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Topography Effects on Ground Response at the Town of Kato Achaia, in the Achaia-Ilia (Greece) M_w6.4, 2008 Earthquake

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ABSTRACT

A concentration of structural damage was observed in the vicinity of the crest of a sloping terrain, in the town of Kato Achaia, following the Achaia-Ilia M_w 6.4, 2008 earthquake. The paper aims at presenting results of seismic response analyses indicating that the observed concentration of damage is related to topography-amplified ground motion. 2-D and 1-D dynamic ground response analyses were performed, with input excitations derived from deconvolution of recorded accelerograms at stations surrounding the slope site. The deconvoluted base motions were then transferred to the site, where an average value of horizontal base acceleration was estimated to be equal to ~0.10g. The results of the analyses indicate that the concentration of damage observed in the vicinity of the crest of the steep slope at the northern part of the town can be interpreted satisfactorily considering spectral amplification up to 30%, due to combined effects of surface topography and local soil conditions.

Introduction

It is now widely recognized that the seismic ground motion caused by earthquake base excitations can be significantly modified by local site effects (Bard and Thomas, 2000). These effects include the surface topography and the near-surface geology effects. In many cases concentration of structural damage occurs at the crest of the slopes and hills (Athanasopoulos et al., 1999). The aim of this paper is to present results of a study on surface topography effects in the Achaia-Ilia, Greece, M_w6.4 earthquake of 8 June, 2008 (Margaris et al., 2010). Parametric nonlinear ground response analyses (2D & 1D) were performed using the finite element code FLUSH-PLUS (EERI, 1991), based on the findings of an extensively geotechnical-geophysical survey carried out following the main event.

Field Observations

The Achaia-Ilia, Greece, M_w6.4 earthquake of 8 June, 2008, caused extensive structural damage and collapse of buildings in the meizoseismal area of Kato Achaia (Margaris et al., 2008). The findings of the reconnaissance conducted by state agencies regarding the heavily damaged structures (marked as "red") are summarized in Table 1 and Figure 1. It is noted that

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the majority of 2-storey and 3-storey buildings suffered heavy damages.

Table 1. Buildings classified as **“red”** (to be demolished) in the town of K. Achaia.

		Type of Structure					
		RC Buildings		**Masonry Buildings**		**RC & Masonry Buildings**	
Number of story	**Total**	**Number of buildings**	**Percentage (%)**	**Number of buildings**	**Percentage (%)**	**Number of buildings**	**Percentage (%)**
1	**3**	-	-	3	100	-	-
2	**28**	-	-	25	89.3	3	10.7
3	**26**	1	3.9	21	80.7	4	15.4
4	**1**	1	100	-	-	-	-

Figure 1. Examples of structural damages in the town of Kato Achaia

Figure 2 shows the geographical distribution of the buildings have suffered severe damage in the town of Kato Achaia. The light red area indicates the concentration of damaged buildings in general, whereas the 50m wide red zone depicts the area of total or partial collapse of buildings. The topography of the study area (the north boundary of the red zone is parallel to the crest of the hill) and the concentration of the damages, indicates that the seismic ground motion was amplified by local site effects.

Geotechnical Data

The geotechnical-geophysical investigation in the area of interest consisted of a combination of exploratory boreholes with sampling and SPT measurements, CPT measurements and in-situ evaluation of low-strain shear wave velocity by Surface Wave Methods (Pelekis and Athanasopoulos, 2011): Spectral Analysis of Surface Waves (SASW), Multi-channel Analysis of Surface Waves (MASW) and Refraction Microtremor (ReMi).

In the satellite image of Figure 3 the locations of exploratory boreholes (G-2 to G-4) and the location of surface wave measurements (#1 to #8) are shown (Batilas et al., 2014). Based on the results of the survey a simplified 2-D shear wave velocity profile (cross section A-A′) was constructed (Figure 4).

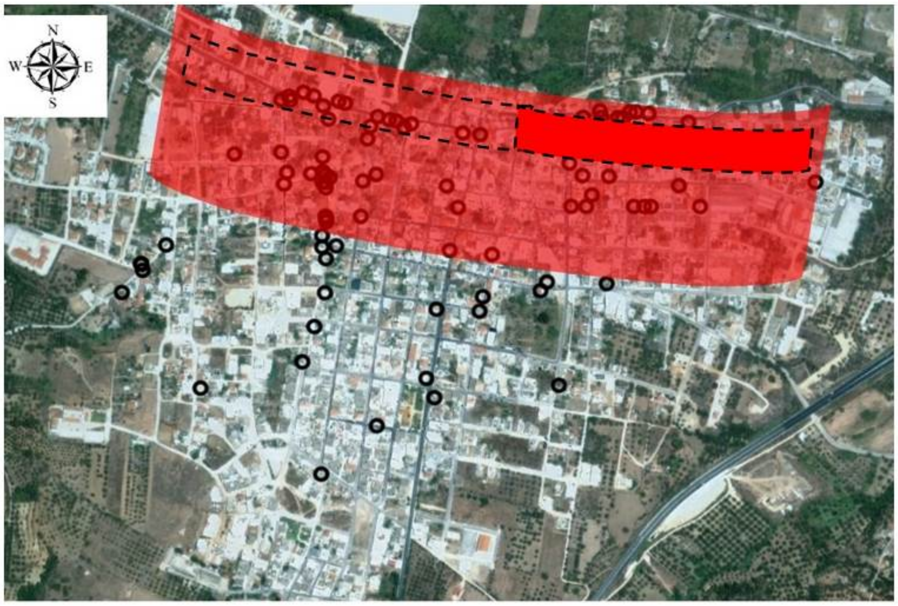
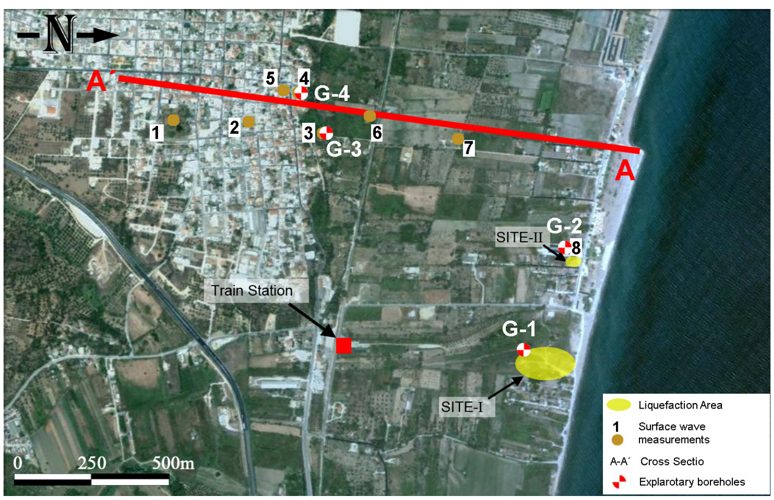


Figure 2. Geographical distribution of “red” buildings in the town of Kato Achaia



Site	Lat. (N)	Long. €	Explarotary borehole/ Vs measurements
1	38°08.536'	21°33.209'	NO / YES
2	38°09.147'	21°33.571'	NO / YES
3	38°08.774'	21°33.269'	G-3 / YES
4	38°08.743'	21°33.176'	G-4 / YES
5	38°08.720'	21°33.168'	NO / YES
6	38°08.846'	21°33.290'	NO / YES
7	38°08.989'	21°33.322'	NO / YES
8	38°08.147'	21°33.571'	G-2 / YES

Figure 3. Satellite image of the town of K. Achaia with the location of in situ tests and exploratory boreholes

Site Response Analyses

The effect of surface topography and near-surface geology on the seismic ground response was studied by conducting 1-D and 2-D equivalent linear numerical analyses (FLUSH-PLUS) and comparing their results. The finite element meshes used in the analyses (based on the simplified 2-D shear wave velocity profile of Figure 4) are shown in Figure 5. Viscous dampers were attached to the lateral boundaries of the meshes to simulate the infinite extent conditions of the meshes. The non-linearity of the soil formations was modeled based on Vucetic and Dobry (1991) G/G_{max} vs. γ_c and D vs. γ_c proposed curves. More specifically two types of curves were used (a) PI=0 for sandy materials and (b) PI=15 for clayey materials.

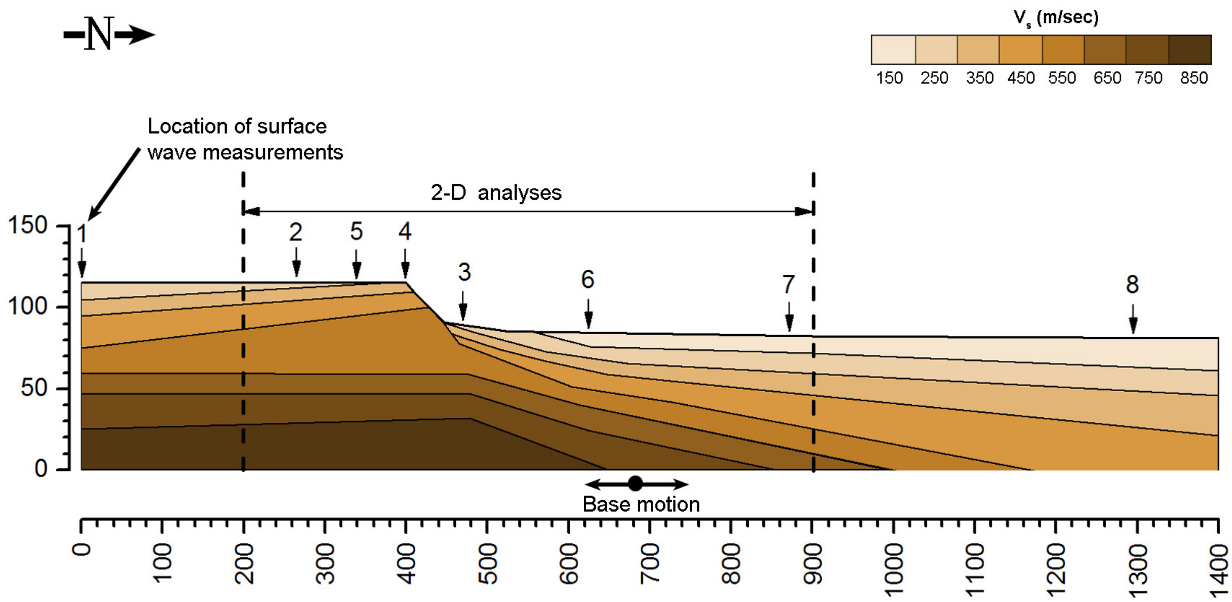


Figure 4. Variation of V_s-depth along the cross section A-A′

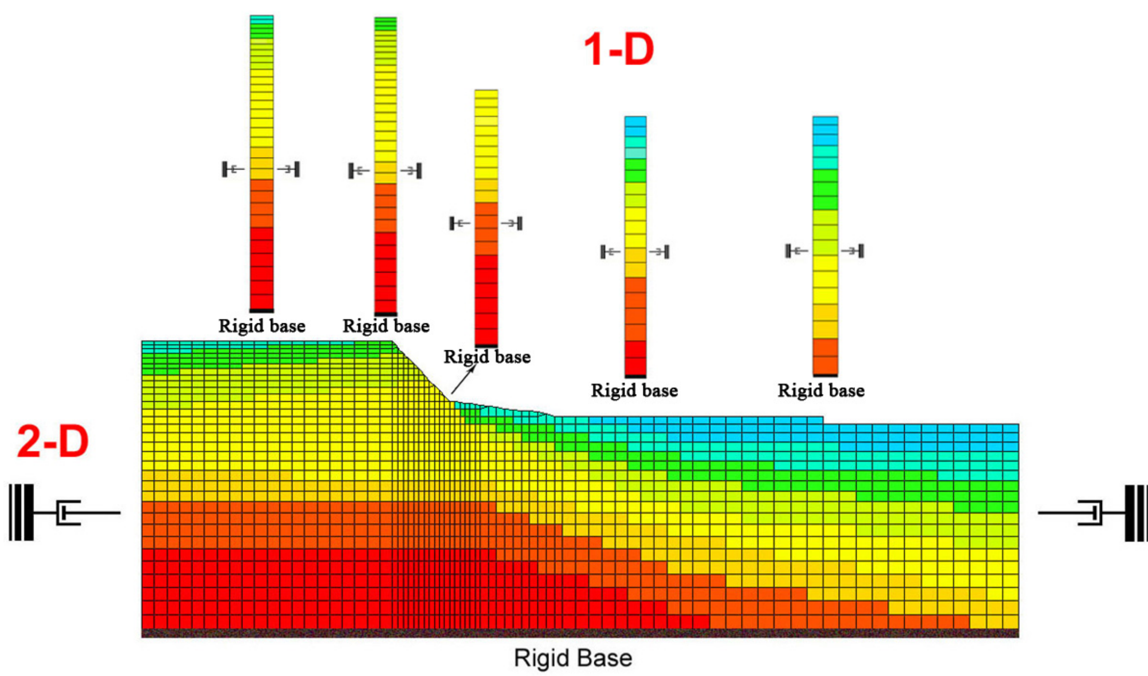


Figure 5. Finite element meshes used for 1D and 2D ground response analyses along cross-section A-A′

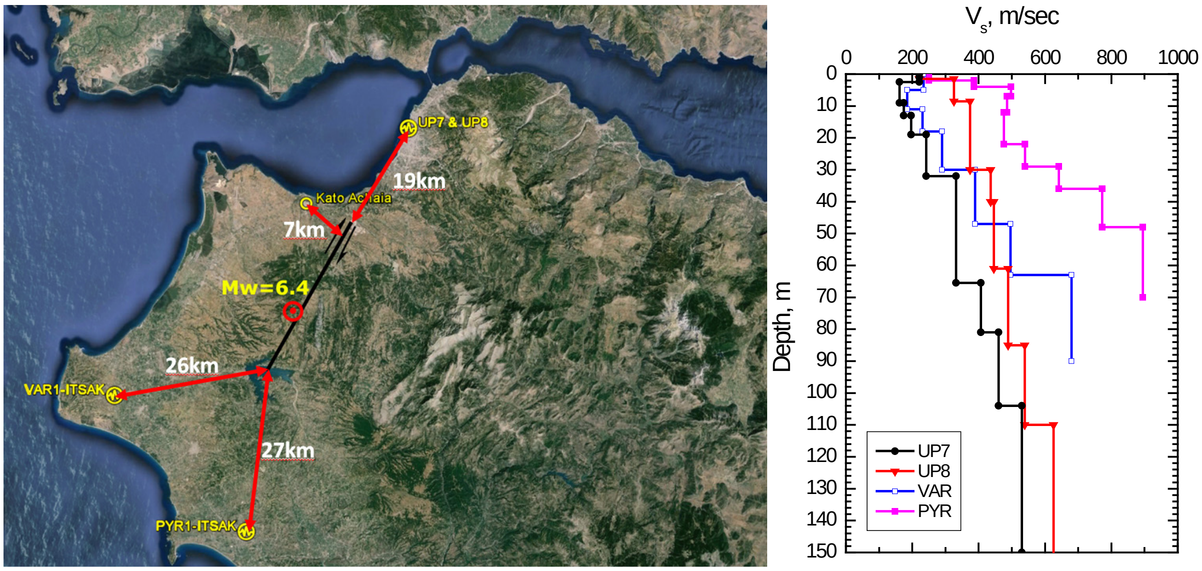


Figure 6. (a) Epicenter, estimated fault trace and location of recording stations (b) V_s-depth curves at the location of recording stations

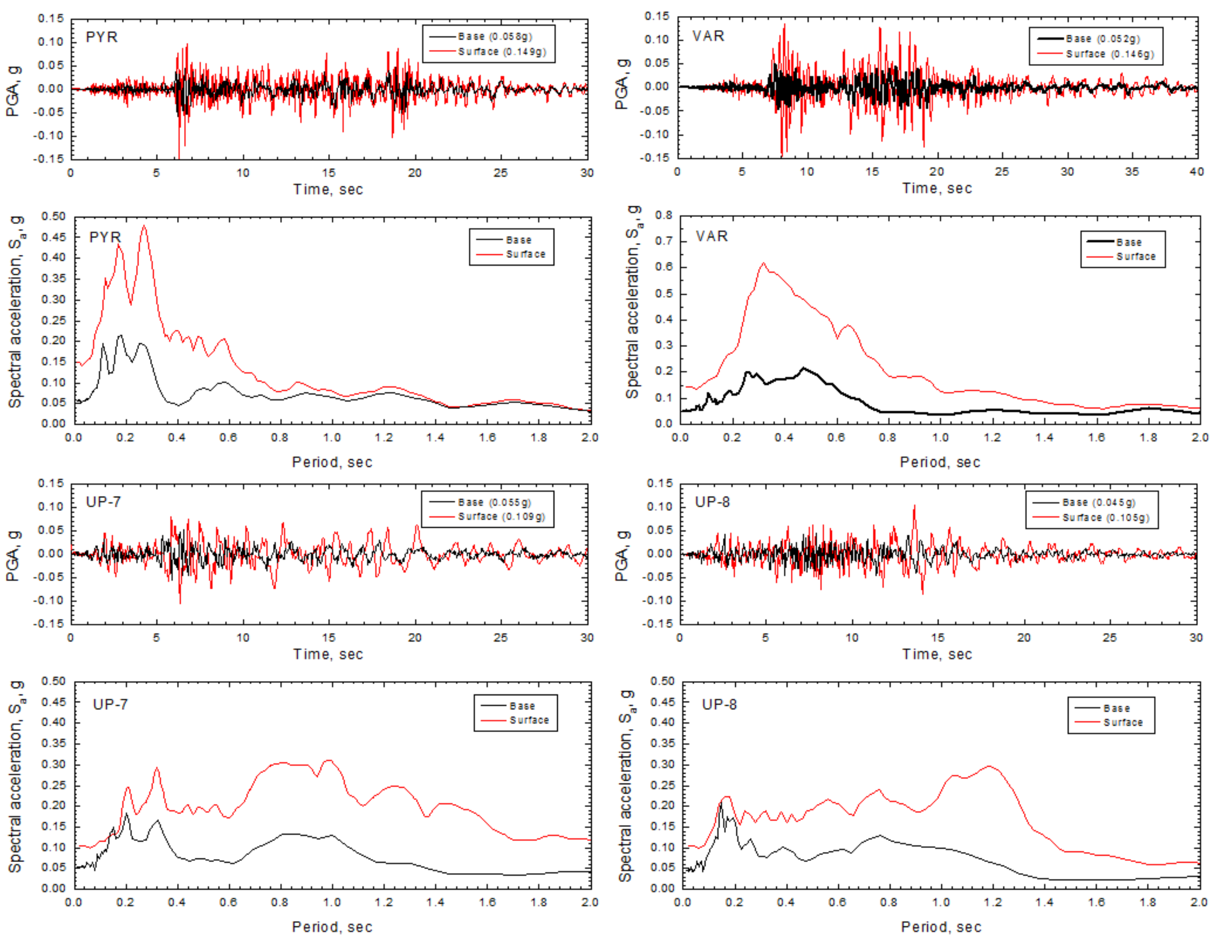


Figure 7. Base motions at the recording stations using deconvolution analyses

Four time histories of the event recorded at accelerograph stations (UP-7, UP-8, VAR and PYR) at distances 19km to 27km from ruptured fault (Figure 6a), were used to response analyses. The two horizontal components of each recording were combined into a single time series according to the methodology proposed by Boore, 2010. The combined horizontal ground motions were then deconvoluted using 1-D analyses to derive the corresponding base (seismic bedrock) motions. The deconvolution analyses were performed using V_s-depth profiles obtained from surface wave measurements at the location of the recording stations (Figure 6b). It is noted that the derived values of seismic bedrock acceleration, were approximately 0.05g (0.045g to 0.058g) at the four recording stations (Figure 7).

Since, neither the bedrock excitation nor peak ground acceleration are known in the area of the city of K. Achaia, a parametric study was conducted by varying the peak value of horizontal acceleration at seismic bedrock. In particular three values of peak bedrock acceleration were used in response analyses a_r=0.05g, 0.1g, and 0.15g.

Results of Site Response Analyses

The diagram of Figure 8a depicts the distribution of peak ground acceleration (PGA) calculated from 2D/1D response analyses with bedrock excitation α_r=0.10g for each motion used, whereas the diagram of Figure 8b shows the average distribution of PGA for all motions used with bedrock excitations α_r=0.05g, 0.10g and 0.15g. From above figure it can been seen that (a) there is no significant difference in PGA distributions related to the motion used, (b) the PGA value is increasing in general moving from coastal zone to uphill area, and (c) the topography affects (amplifies) the PGA value approximately 50m from the crest in uphill direction and 200m in downhill direction. Especially at a distance 200m from the crest, in downhill, direction a dramatic increase of the PGA values (about 50%) occurs due to sedimentary basin edge effect. Since this is an un-built area it is not possible to draw definitive conclusions regarding this part of the town. It is noted that, based on the shakemap reported by the USGS, 2008 (http://earthquake.usgs.gov/earthquakes/shakemap/global/shake/2008taaw/) the mean value of peak ground acceleration at the location of Kato Achaia is 0.37g, which corresponds to the response analyses results using seismic bedrock excitation a_r=0.10g.

In the diagrams of Figure 9 the distribution of spectral amplification ratio is presented for both 1D / 2D response analyses for four period ranges 0.05-0.15sec (1-storey buildings), 0.15-0.25sec (2-storey buildings), 0.25-0.35sec (3-storey buildings) and 0.35-0.45sec (4-storey buildings). From the plots of Figure 9 is observed that the values of spectral amplification ratio (SR) ranging from 2.5 to 4 occur at the crest with a maximum value developing for period T=0.25-0.35sec.

It is noted that, in the period range T=0.15-0.35sec (1-storey and 2-storey buildings) fall the 93% of heavily damaged buildings (classified as “red”). Also, the average spectral amplification at the crest area obtained from 2D analyses is 30% higher than the spectral amplification ratio values 100m away from the crest in the uphill direction. These results are in agreement with the observed pattern of damaged buildings which are concentrated in 50m width zone parallel to the crest of the hill.

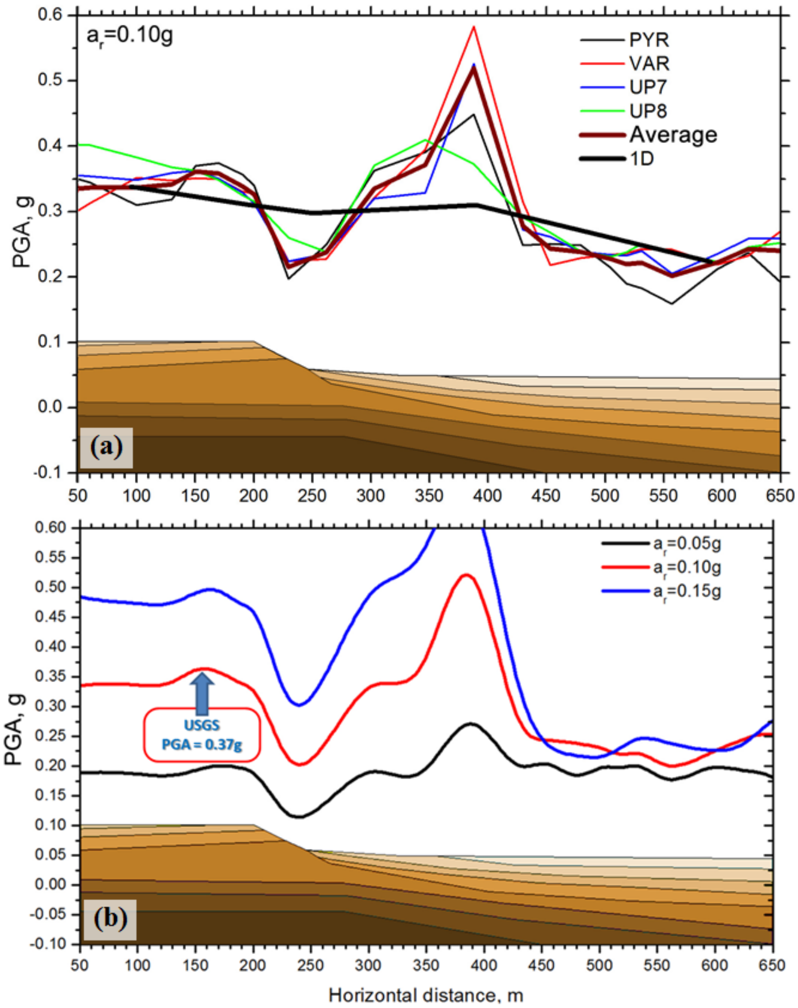


Figure 8. (a) Distribution of 1D / 2D PGA values for bedrock excitation a_r=0.1g, (b) Average distribution of 2D PGA values for bedrock excitation a_r=0.05g, 0.1g, 0.15g

The amplification spectra of Figure 9 clearly indicate that 1D response analyses predicts quite well the ground response at distances 100m and 200m in uphill and downhill direction, respectively, from crest. However, the amplification in the vicinity of the crest can be predicted only by using 2D response analyses.

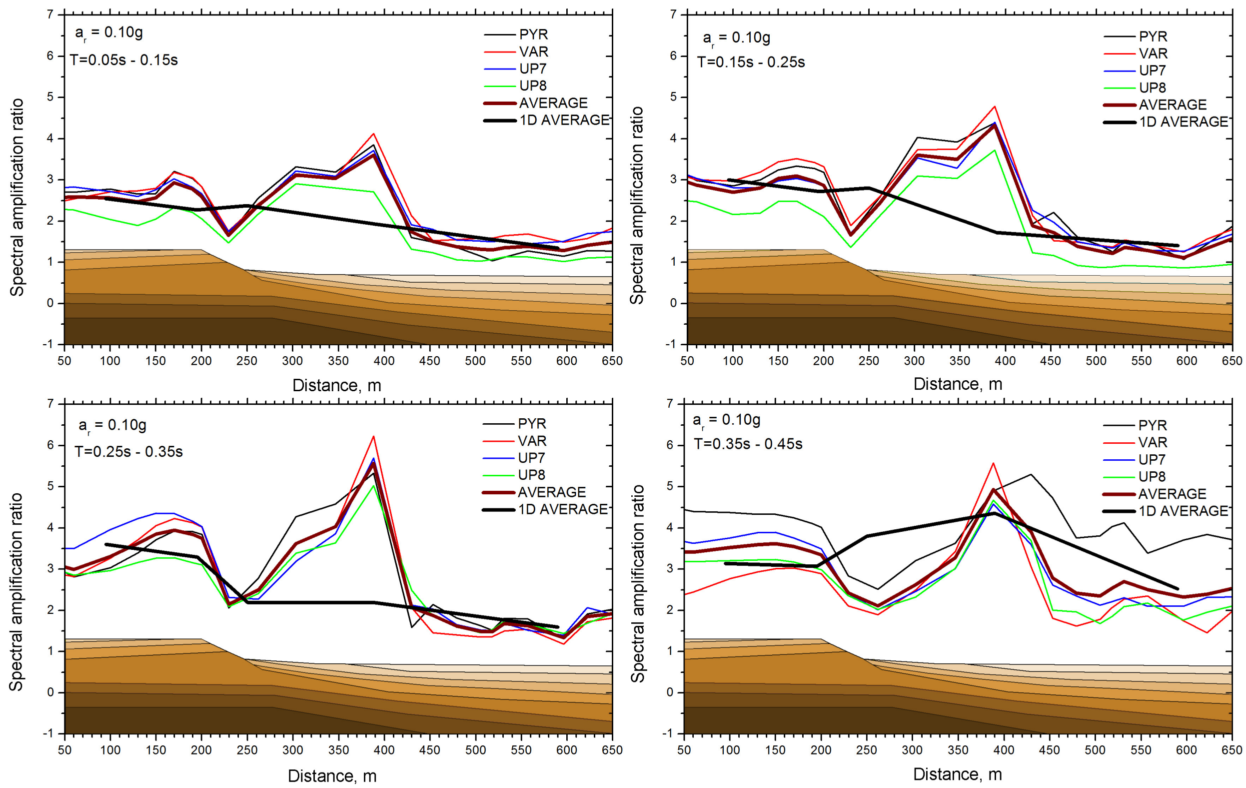


Figure 9. Spectral Amplification Ratios for bedrock excitation a_r=0.1g

Conclusions

The main findings of the present study can be summarized as follows:

a) The dynamic properties of soil formations at the area of K. Achaia were evaluated by extensive geotechnical/geophysical investigation. Additional measurements were also conducted at the sites of four (nearest) accelerograph stations that recorded the seismic event.
b) Based on the measured V_s-depth profiles at the recording stations, the seismic bedrock motion in the area was evaluated through deconvolution analyses (1D equivalent linear response analyses) for each station.
c) The peak value of bedrock motion in the area was estimated to be a_r=0.10g, based on the parametric analyses and the USGS (2008) shakemap.
d) The observed damage pattern is fully compatible with the findings of the 2D seismic response analyses, which indicate 30% amplification of spectral acceleration values in a 50m wide zone, parallel to the crest.

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