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EFFECTS OF SURFACE AND SUBSURFACE TOPOGRAPHY ON STRONG GROUND MOTION AT THE CITY OF AEGION - GREECE

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SUMMARY

In this paper, the effect of surface and subsurface topography is studied along a characteristic cross-section of the Aegion City, Greece, which suffered many damaging earthquakes. This site has the unique feature of combining the good knowledge of local geology, topography and dynamic soil properties, with the existence of a permanent surface and downhole strong motion array that provided several earthquake recordings during the last 2 years. Theoretical approaches (1D, 2D) and analyses of experimental data have been applied at the site in order to reveal the time and frequency domain characteristics of ground motion at both upper and lower parts of the topographic relief. 1D site response analyses proved to be inadequate to simulate successfully the wave propagation pattern in the foothill part, where the down-hole array is, most probably due to complex effects related with the existence of locally generated and laterally propagated from the lateral discontinuities surface waves which are observed on the recordings and the 2D analyses. Both experimental data and theoretical analyses reveal the amplification of all seismic components near the crest and the complicated nature of the wave-field near the foothill.

INTRODUCTION

It has long been recognized that during earthquakes, ground shaking at a particular site is significantly affected by local geology, a term referring not only to thickness and stiffness of soil layers from surface to bedrock, but also to the geometry of the irregular interfaces of soil materials and rock, as well as to the topographic relief. The irregular shape of surface and subsurface topography is very often attributed to be responsible for the focusing and defocusing of seismic energy as they propagate within the irregularity as well as for the generation of surface waves due to diffraction phenomena at the lateral discontinuities that interfere with body waves and lead to complex compositions of seismic wave-field and thus irregular

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distribution of damage (Aki [1], Bard [2], Faccioli [3], Chávez-García [4]).

During the last twenty years, many numerical studies have emphasized the importance of subsurface topography in alluvial valleys or sedimentary basins. It is expected that lateral thickness variations generate local surface waves which are trapped within the soft layers, leading to increased amplifications with respect to classical 1D case. Till recently, there had been little instrumental evidence of the effect of subsurface topography on ground motion and few cases showing the inadequacy of 1D models to explain observed amplifications. Recent experimental studies using data from arrays and well-documented soil structures demonstrated, that the surficial geological structure has a significant impact in the ground motion mainly because it affects the wavefield trapped in sedimentary valleys (Frankel [5], Kinoshita [6], Field [7]). Such strong evidences were reported at EUROSEISTEST site located in northern Greece where recent studies showed that the lateral discontinuities at this shallow sedimentary valley generate locally diffracted surface waves that affect the frequency content and the amplification of seismic motion as well as duration of observed ground motion (Raptakis [8], Chávez-García [9])

After destructive earthquakes (Friuli, Italy 1976, Irpinia, Italy 1980, Chile 1985, Whittier Narrows 1987, Kozani, Greece 1995, Aegion, Greece, 1995 and Athens, Greece 1999), it has been also reported that buildings located at hill tops suffer more intensive damage than those at the base (Brambati et al. [10], Siro [11], Celebi [12], Kawase [13]). There are few but strong instrumental evidence that surface topography affects the amplitude and frequency content of ground motion (Geli et al [14], Faccioli [3], Finn [15], Chávez-García [4] [16], Lebrun [17]). Apparent topographic effects are observed on the abutment of Pacoima Dam in San Fernando 1971 Earthquake (Boore [18]), where an impressively high acceleration of 1.25g was recorded at the crest of a narrow ridge adjacent to the dam in Tarzana station during the Northridge 1994 earthquake. In Europe, weak motion measurements reported similar observations of large amplifications, almost with a ratio of ten, in a narrow frequency band around 5Hz (Bard [19], Nechtschein [20], Chávez-García [16], Lebrun [17]). These effects are related mainly to three physical phenomena: (a) the sensitivity of surface motion to the incidence angle around the critical especially for SV waves, (b) the focusing and de-focusing of seismic waves along the topographic relief and (c) the diffraction of body and surface waves which propagate downwards and outwards from the topographic features and lead to interference patterns between direct and diffracted waves.

Quantification of surface and subsurface topographic effects on seismic ground motion is a very difficult task as many parameters of different nature are involved. The lack of high quality experimental data, helping to better understand the physics of topographic effects and to validate the numerous theoretical analyses and results, makes ambiguous the incorporation of the acquired experience in current seismic code provisions. Nevertheless, although the engineering community is well aware of the effects of subsurface topography on seismic motion and several studies have been performed during the last few years towards the quantification of these effects in a code oriented way (Chávez-García [21], Makra [22]), seismic codes till now does not include any provision on this issue. On the contrary, for surface topography effects, in the framework of the French Code AFPS-1990, and in a draft version of EC8, it is proposed to apply a correction factor for both ridge and cliff-type topographies as a function of the height H and the slope angle i. The so-called aggravation factor is giving an extra amplification of 20% to 40% to the 1D conventional ground motion estimation

COMPLEX SITE EFFECTS STUDY AT AN EXPERIMENTAL SITE IN GREECE

Location of the site

The site is located at Aegion city, in the Gulf of Corinth, one of the most active seismotectonic areas in Europe (Figure 1), with important north dipping WNW-trending active normal faulting. One of these faults is Aegion fault, with an average slope of 40º and an escarpment between 40–100 m high (Figure 1). CORSSA down-hole array has been established at the shoreline of Aegion. The selection of the site accomplishes two basic requirements: a) loose-soft soil materials susceptible to liquefaction and/or significant non-linearity at shallow depths and b) relatively shallow seismic bedrock for the installation of the deepest accelerometric station.

The most recent destructive earthquake occurred in June 1995 (Ms=6.5), causing serious damage in the city of Aegion, built on a sort of terrace, right on the foot wall of the Aegion fault. Part of the city, mainly harbor facilities and small old masonry factory buildings, are on the hanging wall part of the fault along the coastal area. Most of the damages were reported up-hill. The earthquake was recorded in one station (OTE) located uphill where important peak ground accelerations were observed (PGA=0.45g)

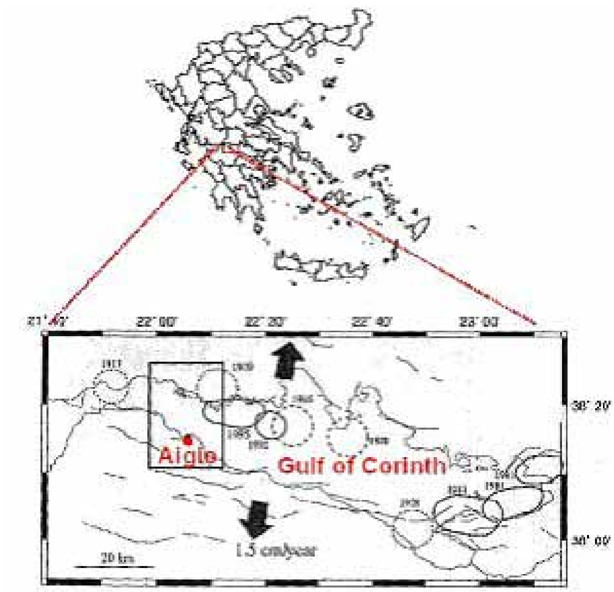
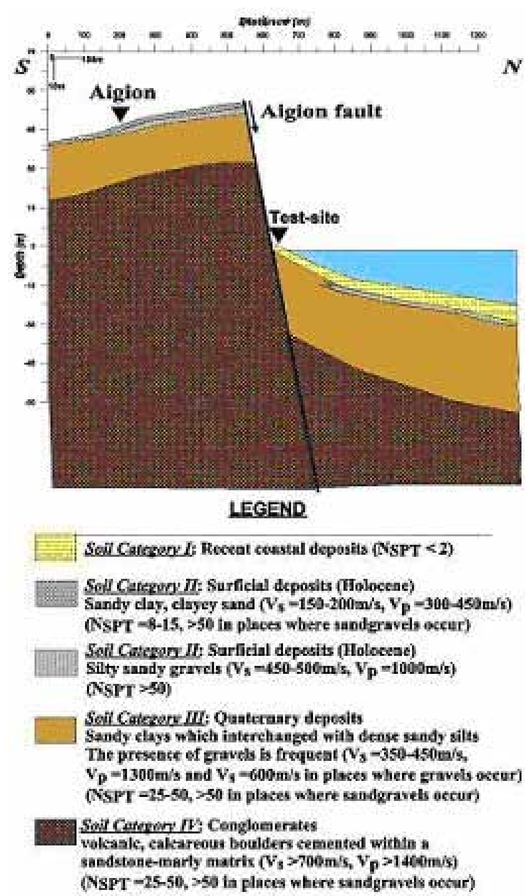


Figure 1. Location (top) and Geological cross-section of the investigated area (right)



Geological – Geotechnical – Geophysical characterization of the CORSSA soft-soil formations

Extensive geological, geophysical and geotechnical surveys have been performed in the site of CORSSA. Geological survey includes detailed geological mapping of the greater area of interest. The geological structure is described by three lithostratigraphic units, the lower one consists of very stiff clays, marls and very dense sands directly overlying the alpine substratum, which consists of Mesozoic limestones. The middle comprises typical deltaic and alluvial fan deposits mostly conglomerates and sands, unconformable overlying the previous unit. The topmost unit characterized by alluvial fan deposits, upon which the Aegion city is located. Holocene and recent deltaic and fluvial deposits, cover unconformable all the rest. Recent geological interpretation indicates the following cross section: 1) in the footwall: 18-27 m of alternation of silt and coarse sand (low Vs) above stiff conglomerates (high Vs); 2) in the hanging wall, same formations covered by loose conglomerates, silty lacustrine deposits and Holocene deposits with low velocity.

Geotechnical campaign included six geotechnical boreholes (of depths: 6m, 2x14m, 31, 60m and 178m), in situ (N_{SPT} and water table measurements) and laboratory tests on intact and remolded soil samples. Resonant column dynamic tests, and geophysical campaign involving borehole (Cross-hole, Down-hole) as well as surface surveys (seismic reflection) are executed to estimate soil stratigraphy and the dynamic soil properties. (P and S-wave velocities – Vp and Vs, shear modulus G_0 at low strains, (G/G_0-γ-D%) curves). The geotechnical profile of CORSSA is given in Figure 2 while Figure 3 illustrates the dynamic soil properties for all soil formations.

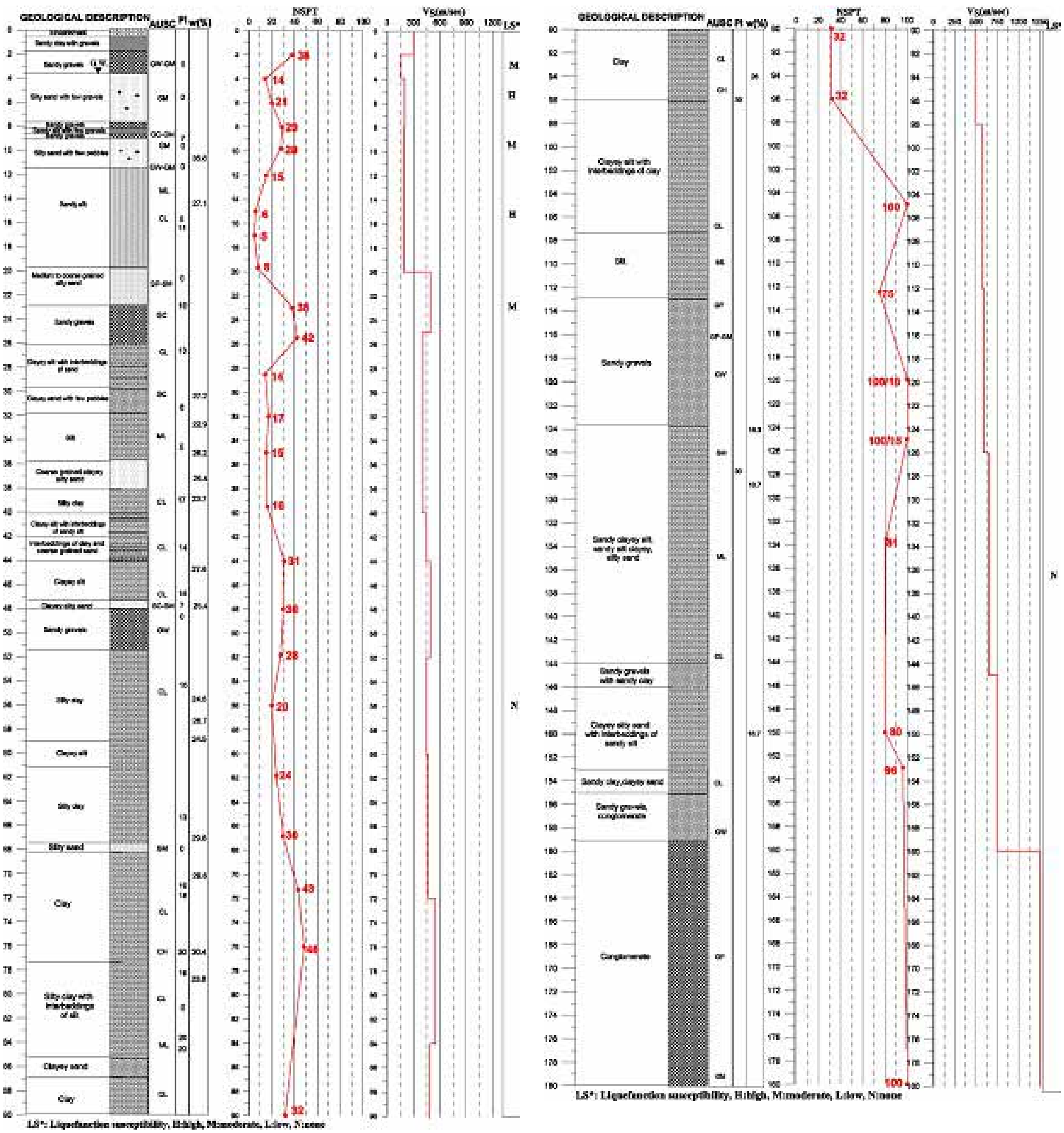


Figure 2. Geotechnical profile at CORSSA site

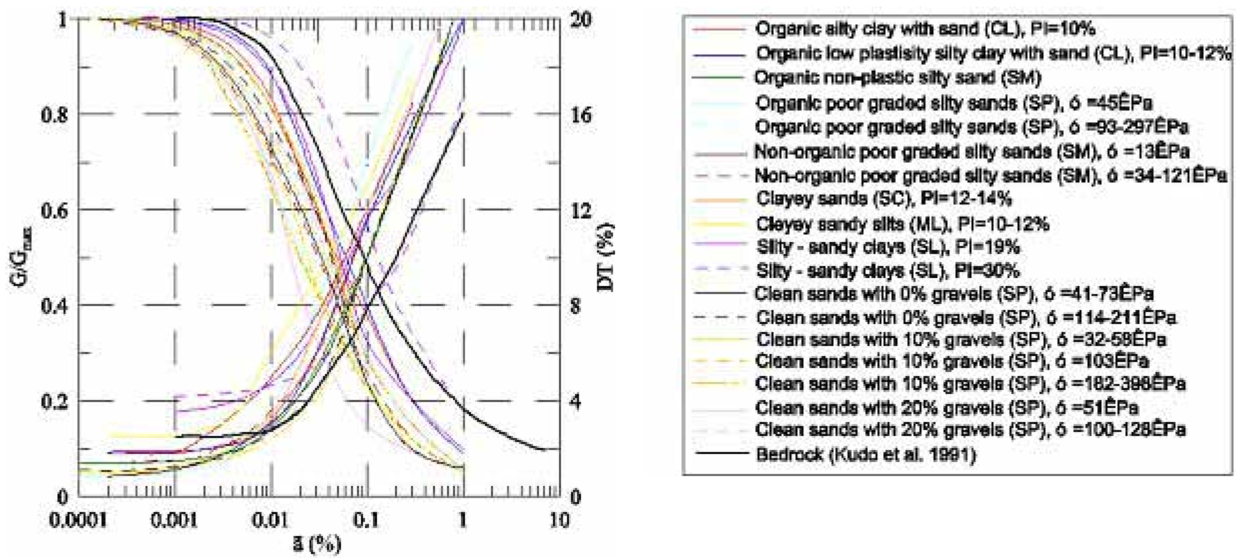


Figure 3. Dynamic soil properties at CORSSA experimental site

Description of CORSSA downhole array

In the framework of the EU funded CORSEIS project, a vertical down-hole array has been installed at the coastal area of Aegion, consisting of five 3-D accelerometers (19 bits, common time) and two dynamic pore pressure transducers (Figure 4). The deepest station is installed at a depth of 178m in the conglomerate layer and the other four stations at -60m -30m -14m and at the free surface. The pore pressure transducers are installed in the saturated loose marine deposits at -6m and -14m depth, where liquefaction phenomena are very prominent. The vertical array CORSSA (CORinth Soft Soil Array) combined with two more surface accelerographs operating on the terrace, form a unique array to study site effects in the presence of soil liquefaction, soil nonlinearities, near or far field conditions and topographic surface and subsurface irregularity.

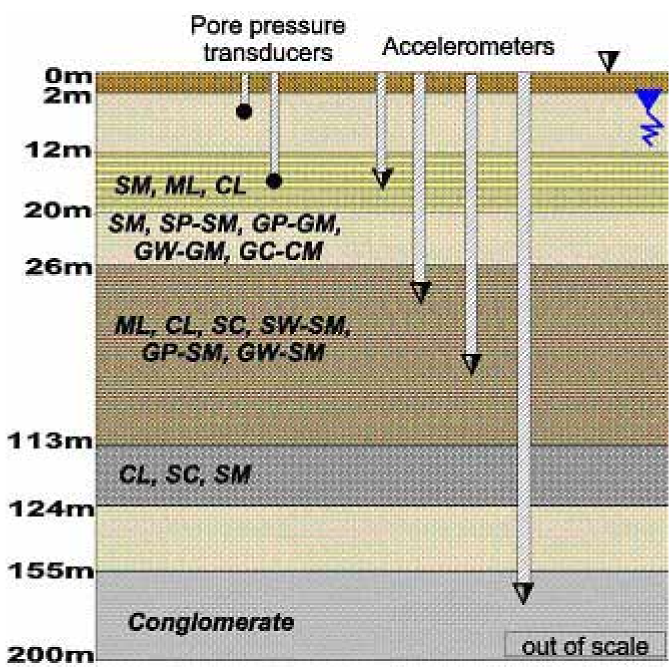


Figure 4. Layout of CORSSA down hole array

Preliminary instrumental approach of site effects

Recordings of 14 events (Table 1) were selected in order to calculate empirical transfer functions for all depths in which 3D accelerometers were installed. The horizontal components of all recordings were rotated according to the Aegion fault orientation. In this way, the radial component for depths has a normal direction to the fault plane, which is very similar to the N–S orientation, while the transverse coincide with the E–W one. Two empirical techniques were used; the horizontal to vertical component, HVSR, and the standard spectral ratio, SSR considering as reference station the deeper downhole accelerometer at 178 m depth.

Table 1. Short list of earthquakes recorded at CORSSA array.

	DATE	GMT	φ	λ	DEPTH	Mw
1	30:05:2002	17:18:50.17	37.500N	22.068E	5km	3.6
2	30:05:2002	21:44:00.00	37.530N	21.950E	8km	4.0
3	18:06:2002	22:21:21.78	38.323N	22.040E	5km	2.9
4	07:07:2002	05:30:41.10	37.933N	22.299E	5km	3.5
5	01:08:2002	20:50:19.68	37.833N	20.619E	7km	3.7
6	03:08:2002	08:44:57.30	37.811N	21.052E	5km	3.9
7	30:09:2002	19:58:12.07	37.670N	21.105E	10km	3.9
8	13:10:2002	14:51:51.75	38.180N	22.236E	10km	3.2
9	17:10:2002	22:39:28.69	38.392N	21.935E	10km	2.7
10	20:10:2002	06:01:07.00	39.282N	23.639E	21km	2.3
11	26:10:2002	18:19:45.24	38.224N	22.871E	10km	3.3
12	09:11:2002	21:49:50.63	37.363N	22.516E	24km	4.4
13	13:11:2002	21:55:40.00	38.440N	22.040E	20km	3.2
14	23:11:2002	01:14:33.02	38.091N	22.705E	17km	3.6
*	07:06:2002	06:23:49.00	38.140N	22.020E	5km	3.7
*	04:04:2002	07:55:50.46	37.963N	21.083E	5km	4.2

The resulted average HVSR ratios for both horizontal components from the top to the bottom show two dominant resonant frequencies at 0.48 and 0.82 Hz (Figure 5a). The level of peak amplitudes at the fundamental frequency 0.48 Hz seems to be quite constant, from 2 to 3, at all depths at the first 57 m. This frequency, if it is real, indicates that the depth of the bedrock is of several hundreds of meters. The second peak, at 0.82 Hz, is slightly larger and wider than the first one. Transfer functions at the deepest station do not present any important amplification for a large frequency band up to 10 Hz. This indication guarantees that this station could be used as reference site for the use of the SSR technique.

Average SSR ratios for all events used in HVSR, at all depths and for both components have been also calculated. (Figure 5b). Average spectral ratios of radial component, at all depths, present a clear peak at 0.95 Hz with larger amplitude than the transversal one. On the contrary, the resonant peak of the transverse is not homogeneous presenting two peaks close to each other at 0.88Hz and 095 Hz. This is an indication that strong interactions between different wave-types take place at this site. The amplification level at all depths is ranging between 6 and 10, except for 14m, where peak amplitudes are larger.

All these are indications of the so-called “edge effect” which is expressed in cases where a strong lateral variation of the geologic materials exists, such as this of the Aegion seismic fault. To clarify the effect of the strong lateral variation, the HVSR of one of the two commonly recorded events (signed with * in Table 1) was calculated at the site, called OTE, 0.5 km from the CORSSA on the foot-wall. Figure 6 shows the HVSR at site OTE together with that at the CORSSA array at the depth of 14 m, since this event was not recorded at the surface. The ratios differ considerably in the amplified resonant frequencies while the amplitude level is similar; at site OTE the amplification is observed at frequencies between 3 and 4 Hz and at site CORSSA between 0.5 and 1 Hz.

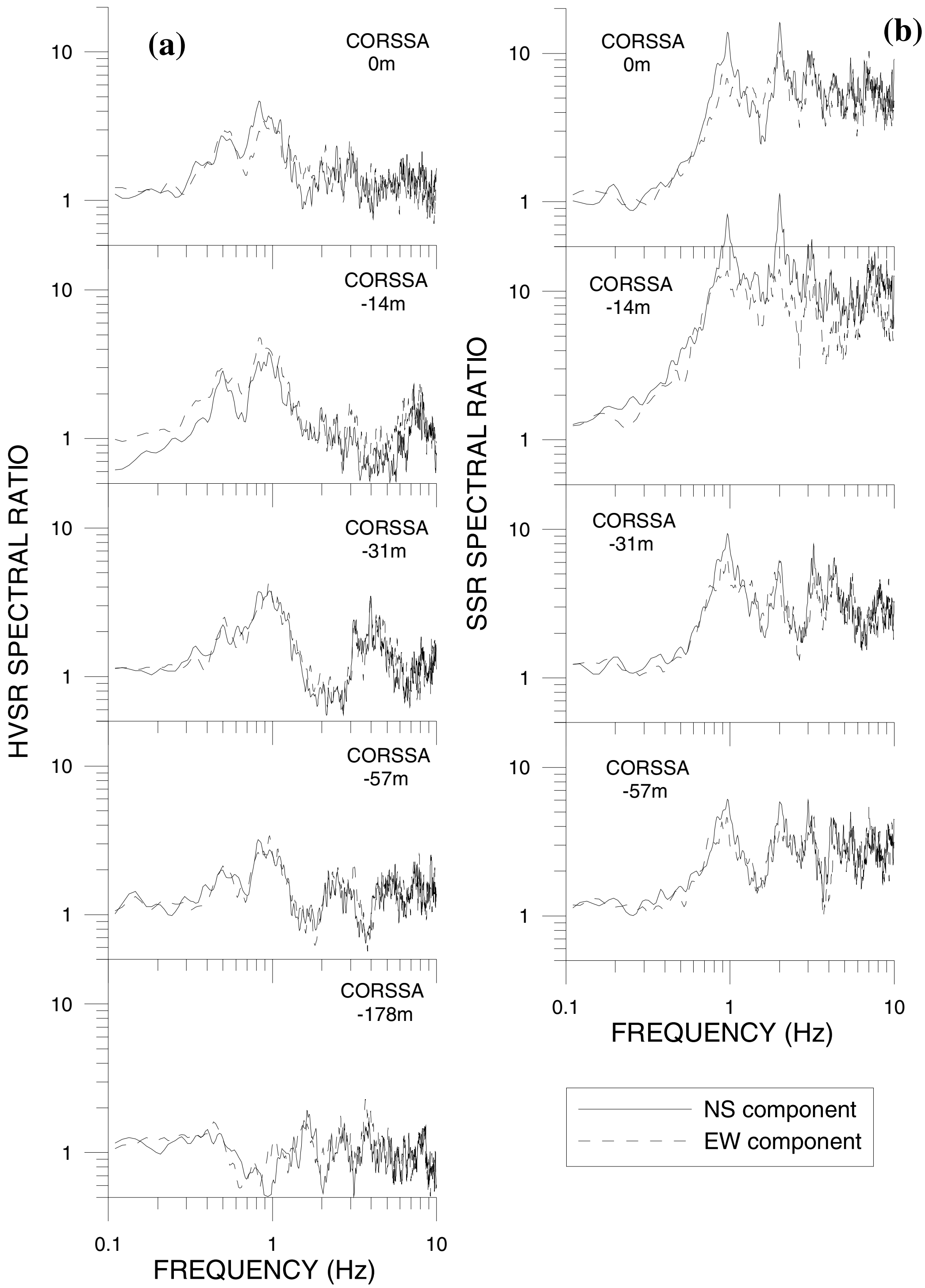


Figure 5. Average HVSR (a) and SSR (b) spectral ratios at two locations

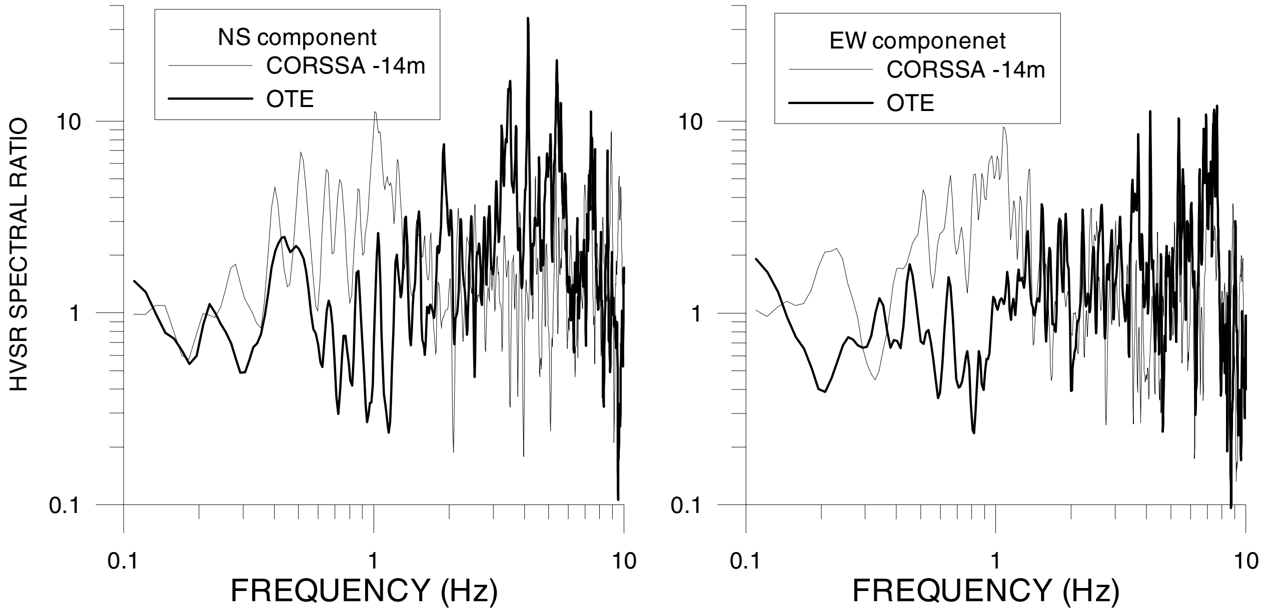


Figure 6. HVSR spectral ratios of the acceleration time histories of an event recorded simultaneously at CORSSA –14m and OTE site.

However, the observations in frequency domain give only partial image, since no information about the wave content and the time duration is depicted. For this reason, the simultaneous recordings of the closer event at both sites OTE and CORSSA are shown together in figure 7. To identify the wave content, all signals of all three components have been filtered with a Butterworth recursive low – pass filter with a corner frequency of 4.5 Hz. It is observed in all three components that the duration of shaking is four times larger for the transversal component at site CORSSA compared to the site OTE. It is clear that this duration of shaking is due to the surface waves generated at the topographic relief and lateral geological variation consisting of the Aegion fault. The longer duration of the transverse component is consistent with the lateral propagation of Love waves, which are propagating from the fault towards the Corinth Gulf. The fact that both radial and vertical components present similar attributes with the transverse one shows the propagation of the Rayleigh waves together with the Love ones. These surface waves are observed at all depths at the CORSSA array. This is a strong indication of the effect of the fault and the topography on the wave – field content, the wave – propagation pattern, and the characteristics of site response.

1D ground response analyses

Preliminary 1-D linear elastic analyses of small events using as input motion the recorded signal at -178m (Pitilakis [23]), proved that 1-D modeling is unable to successfully simulate the time characteristics (peak acceleration, frequency content and duration) of the recordings in the foothill of Aegion. An example is depicted in figure 8. Given the geometrical characteristic of the site due to the existence of the fault which forms a strong lateral material and geometrical discontinuity, this inefficiency of 1D modeling to represent the characteristics of the recordings is most likely due to lateral propagation of surface waves locally generated at the discontinuity. Due to the fact that the array is located very close to the discontinuity, the interference between the locally generated surface waves with the direct body waves will probably take place in a very short time after the first S-wave arrivals, thus it would be quite difficult to make a clear distinction between them. On the other hand, this situation might have an effect on the level of the peak ground acceleration. To clarify this, a 2-D wave propagation analysis is deemed necessary as well as a thorough investigation of the time and frequency characteristics of observed ground motion at the downhole array.

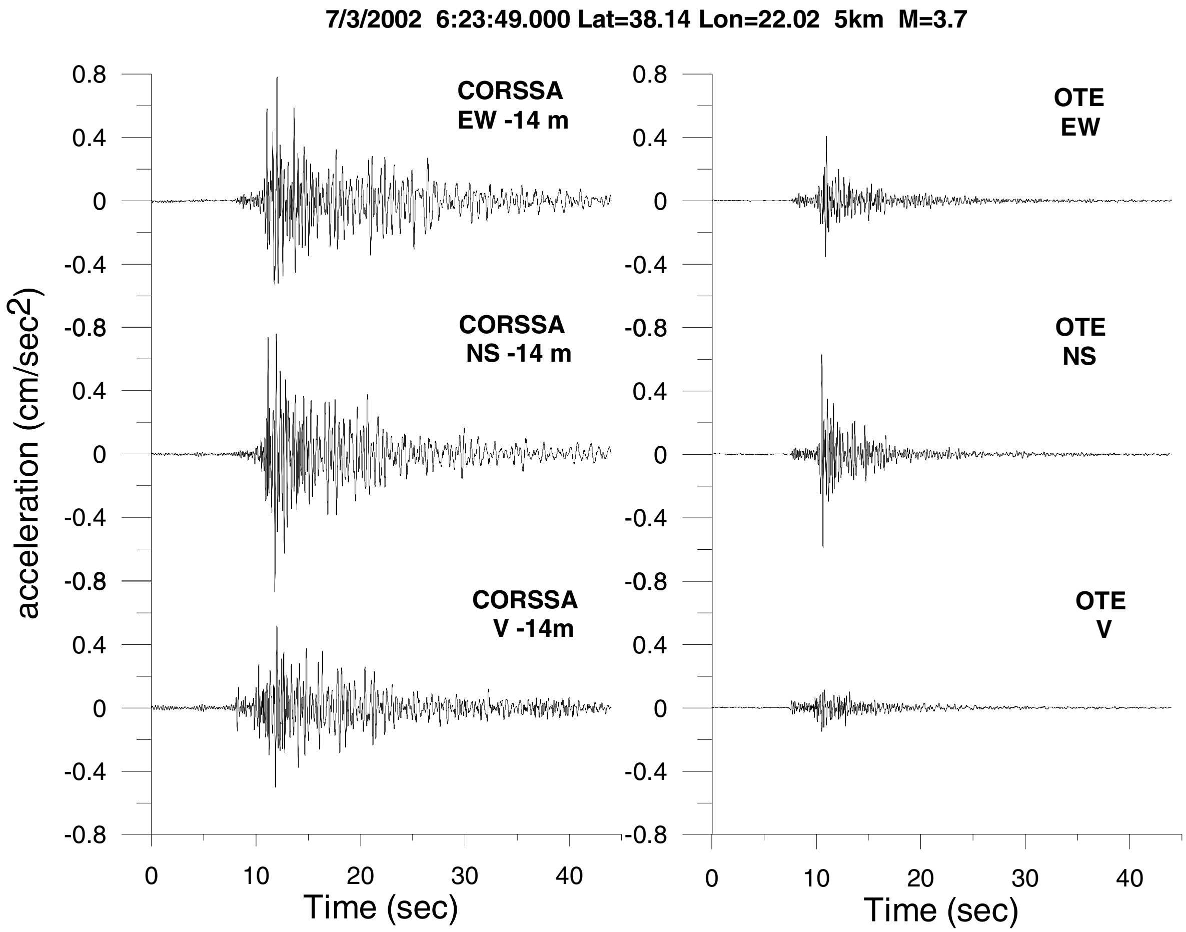


Figure 7. Simultaneous accelerations time histories at OTE site and CORSSA

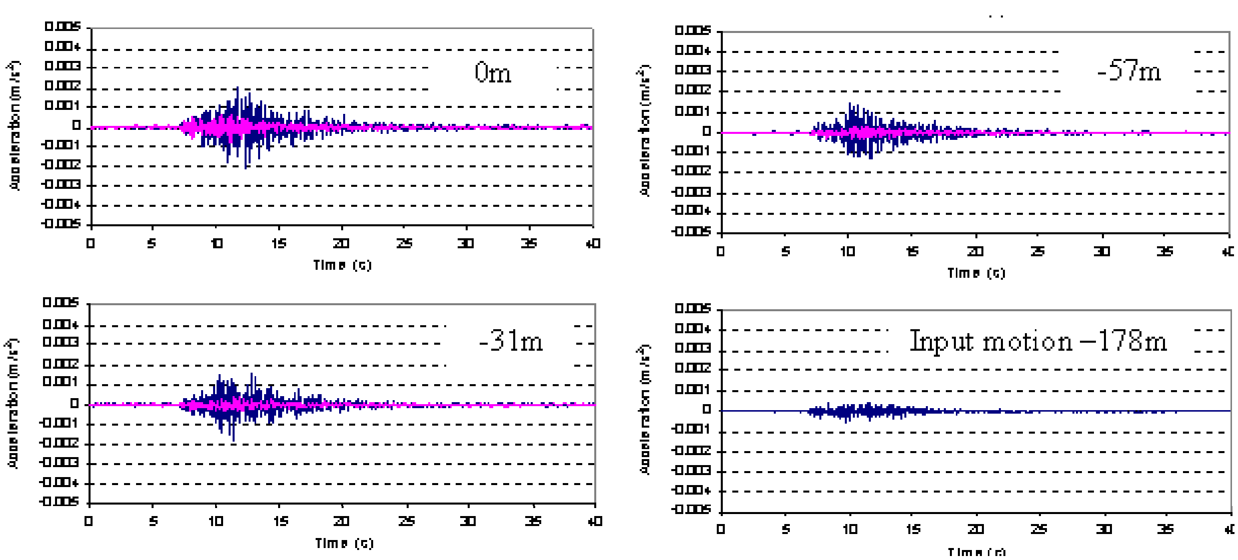


Figure 8. Recorded (blue) and computed (1D SH - wave) time histories (magenta) for a small event.

Preliminary 2D ground response analysis

The motivation of that analysis was to a-priori study the effects of surface and subsurface topography in the spatial variation and the intensity of ground shaking along the irregularity using simple input Ricker type motions (Ktenidou [24]). A two-dimensional wave propagation analysis was performed using the finite difference code FLAC (Itasca, Inc.).

For the purposes of the 2D ground response analysis, a simplified 2D cross section and finite difference model was adopted (Figures 9 and 10). Material properties are given in Tables 2 and 3 for the uphill (OTE) and hanging wall (CORSSA) soil profiles. Uniform damping was assigned to be of Rayleigh type (frequency dependent) taking into account the sum of both stiffness and mass components. The center frequency is chosen at 1.4Hz in order to lie almost in the center of predominant input frequencies. A parametric analysis on the damping value was performed to see the effect of this kind of damping on the results. In this work, the results for $\xi=2\%$ are presented.

The maximum frequency for which results present numerical stability is 6Hz according to material and grid properties. Input motions have the time dependency of a Ricker wavelet with central frequencies of 0.88Hz, 1.43Hz and 3Hz. These frequencies were selected in order to cover a wide range of frequencies yet to coincide with the fundamental frequencies of the soil profiles in the uphill and hanging wall part of the mesh. They were assigned as a vertical propagated SV wave. All analyses are in the linear elastic range.

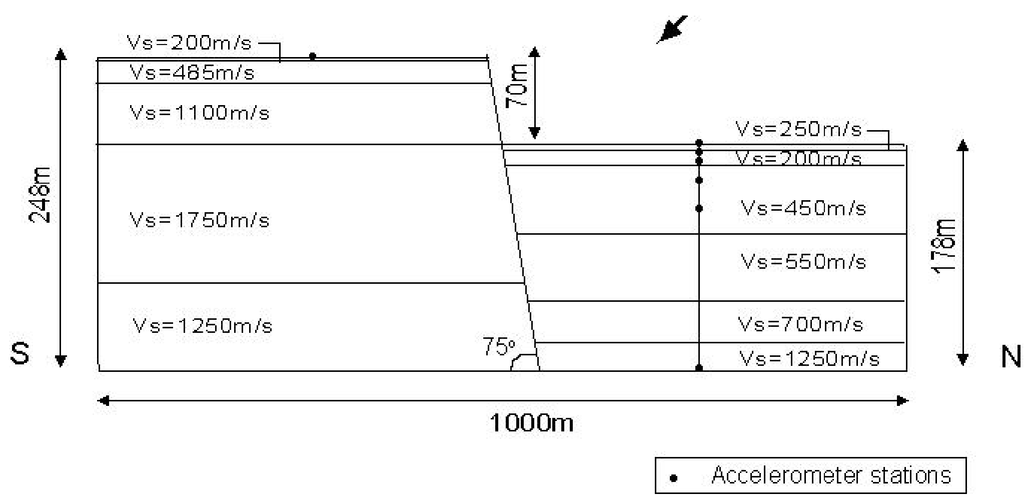


Figure 9. Simplified cross-section of the area

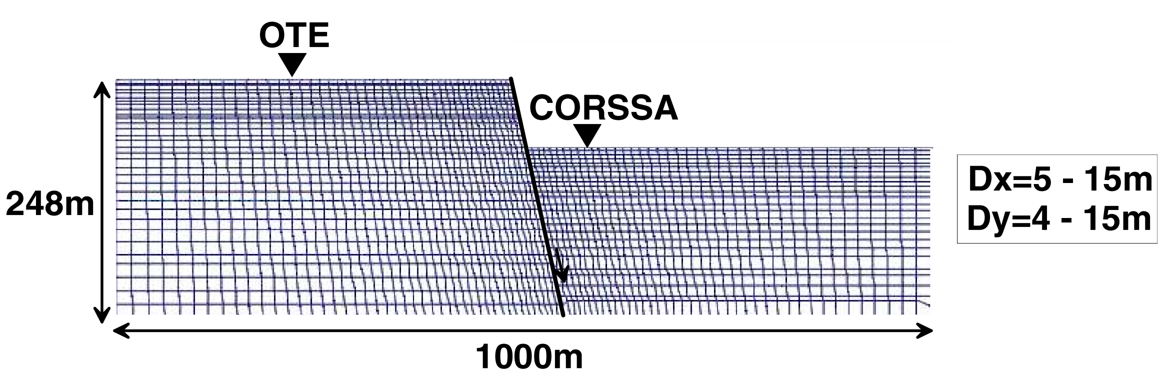


Figure 10. Finite difference discretization of the analyzed configuration.

Table 2. Material properties and OTE soil profile (uphill)

Depth [m]	Thickness h[m]	d [kN/m^3]	v	Vs [m/s]	Go [MPa]	K [MPa]
0~4	4	20	0.3	200	81.5	176.7
4~22	18	21	0.3	485	503.5	1091
22~70	48	22	0.35	1100	2715.5	8140.7
70~182	112	22	0.35	1750	6868	20604
182~248	66	22	0.32	1250	3229.4	7894

Table 3. Material properties and CORSSA soil profile (hanging wall)

Depth [m]	Thickness h[m]	d [kN/m^3]	v	Vs [m/s]	Go [MPa]	K [MPa]
0~4	4	20	0.3	250	127.4	276.1
4~22	16	19.5	0.3	200	79.5	172.3
22~72	52	20.5	0.3	450	423.2	916.9
72~126	54	21	0.3	550	647.6	1403
126~160	34	21	0.3	700	1048.9	2272.7
160~178	18	22	0.35	1250	3504.1	10512.2

Figure 11 shows the distribution with depth (at the points depicted at the top of the figure) for the 3 Ricker type SV input motion of the horizontal component of predicted ground motion at 4 characteristics sections of the mesh. Based on these preliminary results, the main conclusions that could be draw is of a qualitative nature because a P-incident analysis and the combination of both (for P and SV) horizontal as well as vertical components are necessary to obtain a more reliable quantitative estimation. Bearing in mind the restrictions of our analysis, the main conclusions could be summarized as follows taking into account the physical phenomena that are expected to affect ground motion.

As it concerns the uphill part of the model where surface topography effects are expected to affect ground motion, (in general amplifying it), it is observed that for input motion with f (Hz) far from the predominant frequency of this part of the mesh, amplification is rather minor. On the contrary, for the Ricker input with f=3.0Hz (similar to dominant frequency at it has been found from the recordings), although no significant differences in the acceleration waveforms is observed, the peak acceleration at the crest is greater than that at OTE site. Having in mind that the only difference between these two sites are the distant from the fault, the difference in the level of the peak ground could be attributed to the phenomena that are related with the surface topography. Figure 12 shows the variation with the distance from the fault of the horizontal accelerations time histories. The maximum peak ground acceleration is observed just at the crest while at the distance of 100m from the crest the minimum peak ground acceleration is depicted. This variation of peak acceleration along the uphill part of the model may be attributed with the constructive and destructive interference of direct with reflected, refracted and diffracted waves at the lateral discontinuity.

The situation is more complicated as regards the hanging wall part of the model. For all input motions used, there is a clear difference in the synthetic time histories between the site located 5m away from the foothill and CORSSA (Figure 11). Peak acceleration and waveforms (frequency content and duration) with depth are quite different between the two sites and this may attributed to the different soil profiles underneath these sites but mainly to the locally generated at the discontinuity and laterally propagated surface waves which seem to affect ground motion at all depth points related with CORSSA site in a qualitative agreement with the empirical results discussed in a previous section. The variation with distance from the lateral discontinuity of synthetic time history (Figure 12) shows that peak acceleration and duration of motion is increases with increasing distance from the fault, a fact which is expected taken into account the nature and the physics of the lateral propagation of surface (Rayleigh) waves.

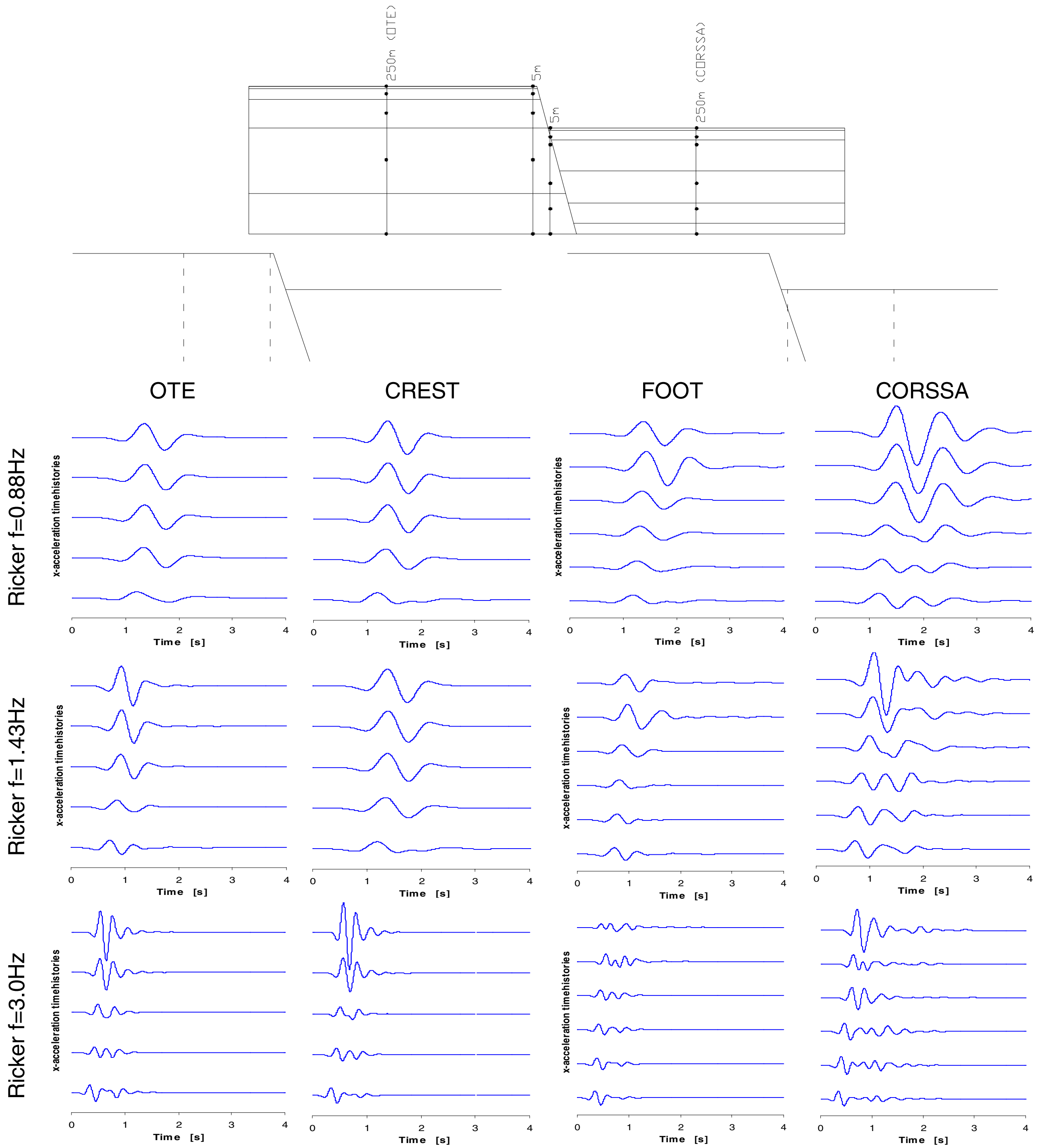


Figure 11. Horizontal accelerations time histories distribution with depth at characteristics cross-sections and points of the mesh. Scale is common to all traces corresponding to the same input motion.

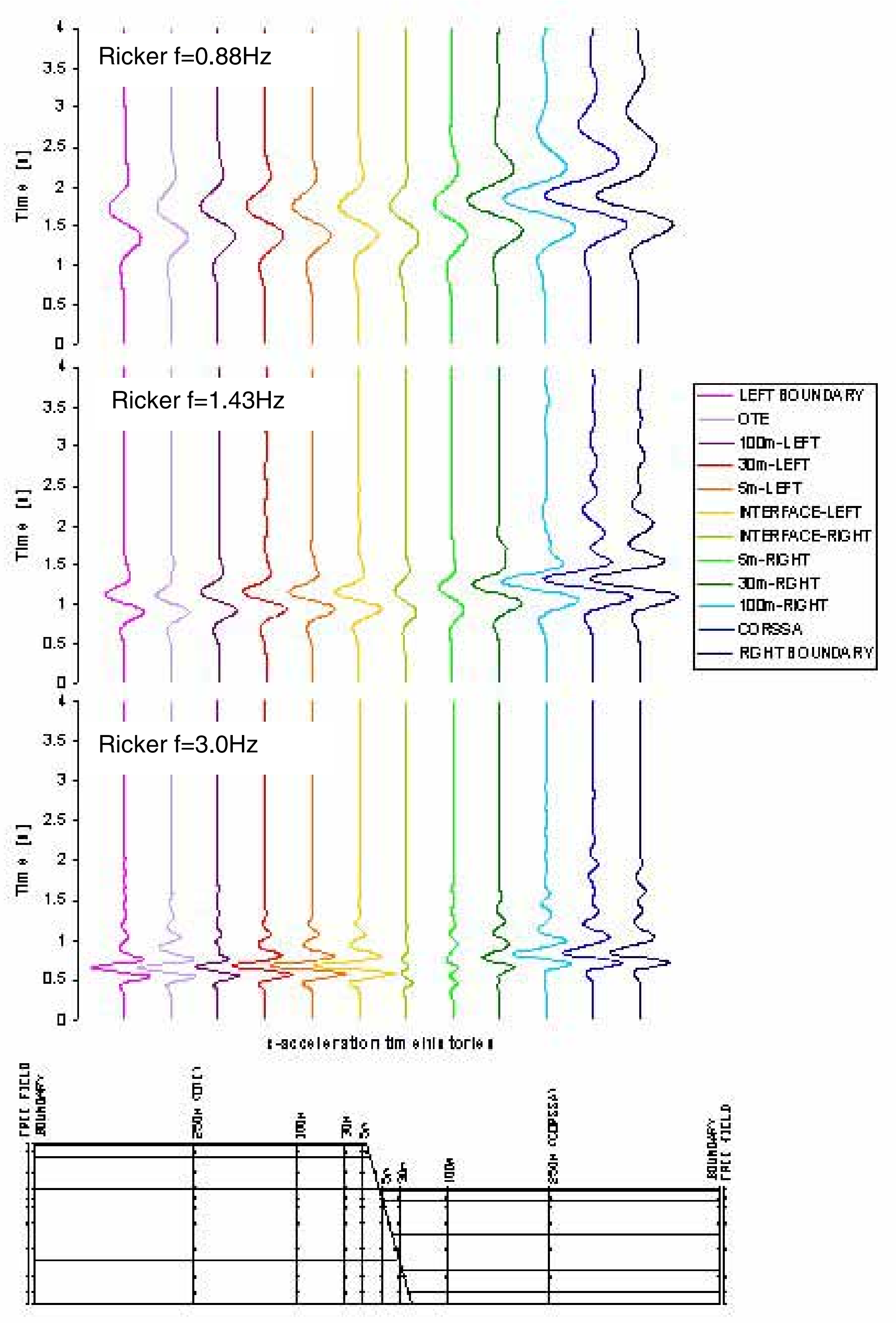


Figure 12. Horizontal accelerations time histories variation with distance from the lateral discontinuity at the surface. Scale is common to all traces corresponding to the same input motion.

CONCLUSIONS

In this paper, the effect of surface and subsurface topography is studied along a characteristic cross-section of the Aegion City, Greece. This site has the unique feature of combining the good knowledge of local geology, topography and dynamic soil properties, with the existence of a permanent surface and downhole strong motion array that provided several earthquake recordings during the last 2 years.

Recordings of 14 events were used to study the effect of surface and subsurface topography on amplitude, frequency content and duration of observed ground motion. Experimental study of site effects has shown indications of the so-called "edge effect" which is expressed in cases where a strong lateral variation of the geologic materials exists, such as this of the Aegion seismic fault. The difference in the duration between two sites, one located uphill and the other at the foot is another indication of the existence of low frequency surface waves generated at the topographic relief and lateral geological variation of the Aegion fault, thus modifying the characteristics of site response.

Theoretical approaches (1D, 2D) have been applied at the site in order to reveal the time and frequency domain characteristics of ground motion observed in the recordings at both upper and lower parts of the topographic relief. 1D site response analyses proved to be inadequate to simulate successfully the wave propagation pattern in the foothill part, where the down-hole array is located. On the contrary, preliminary synthetic time histories of 2D analyses showed that they are in a qualitative (for the time being) agreement with the time and frequency characteristics of observed ground motion thus representing more faithfully the effect that are related with the existence of locally generated and laterally propagated from the lateral discontinuities surface. Theoretical analyses reveal the amplification of all seismic components near the crest and both experimental study and theoretical analyses manifest the complicated nature of the wave-field near the foothill. Nevertheless, in order to draw safe quantitative conclusions in a code oriented way regarding both the effect of surface and subsurface topography to seismic motion, a more thorough analysis of the results and their systematic confrontation with observed ground motion is in progress.

REFERENCES

1. Aki, K., 1988. Local site effects on strong ground motion. In J. L. VonThun (ed.), *Earthquake Engineering and Soil Dynamics II* - Recent Advances in Ground Motion Evaluation, June 27-30, Park City, Utah, pp. 103-155.
2. Bard, P.-Y., 1994. Effects of surface geology on ground motion: recent results and remaining issues. *Proc. 10th European Conf. Earthq. Eng.*, Vienna, Austria, 1, 305-323.
3. Faccioli, E., 1991. Seismic amplification in the presence of geological and topographic irregularities. *Proc. 2nd Intern. Conf. On Recent Advances in Geotechnical Earthq. Engrg.and Soil Dynamics*, March 11-15, St. Louis, Missouri, S. Prakash (etidor), Univ. of Missouri-Rolle, 2, 1779-1797.
4. Chávez-García, F.J., L.R. Sanchez & D. Hatzfeld, 1996. Topographic site effects and HVSR. A comparison between observations and theory. *Bull. Seism. Soc. Am.*, 86, 1559-1575
5. Frankel, A., S. Hough, P. Friberg & R. Busby, 1991. Observations of Loma Prieta aftershocks from a dense array in Sunnyvale, California. *Bull. Seism. Soc. Am.*, 81, 1900-1922.
6. Kinoshita, S., H. Fujiwara, T. Mikoshiba & T. Hoshino, 1992. Secondary Love waves observed by a strong motion array in Tokyo Lowlands, Japan. *J. Phys. Earth*, 40, 99-116.
7. Field, E.H., 1996. Spectral amplification in a sediment filled valley exhibiting clear basin-edge-induced waves. *Bull. Seism. Soc. Am.*, 86, 991-1005.
8. Raptakis, D., F. J. Chávez-García, K. Makra & K. Pitilakis, 2000. Site effects at EUROSEISTEST - I. Determination of the valley structure and confrontation of observations with 1D analysis. *Soil Dyn. Earthq. Engnr,* 19(1), 1-22.
9. Chávez-García, F. J., D. Raptakis, K. Makra & K. Pitilakis, 2000. Site Effects at EUROSEISTEST - II.

Results from 2D numerical modeling and comparison with observations. *Soil Dyn. Earthq. Engnr,* 19(1), 23-39.

10. Brambatti, A., E. Faccioli, E.B. Carulli, F. Culchi, R. Onofri, S. Stefanini & F. Ulcigrai, 1980. *Studio de microzonizzazione sismica dell' area di tarcento (Friuli). Edito da Regiona Autonoma Friuli-Venezia-Giulia (in Italian)*
11. Siro, L., 1982. Southern Italy November 23, 1980 earthquake. *Proc. 7th European Conf. Earthq. Engrng*, September 20-25, Athens, Greece, Technical Chamber of Greece (Editor), 7, 419-429.
12. Celebi, M., 1987. Topographical and geological amplifications determined from strong motion and aftershock records of the 3 March 1985 Chile earthquake. *Bull. Seism. Soc. Am.*, 77, 1147-1157.
13. Kawase, H. & K. Aki, 1990. Topography effect at the critical SV wave incidence: possible explanation of damage pattern by the Whittier-Narrows, California earthquake of 1 October 1987. *Bull. Seism. Soc. Am.*, 80, 1-22.
14. Géli, L., P.-Y. Bard & B. Jullien, 1988. The effect of topography on earthquake ground motion: a review and new results. *Bull. Seism. Soc. Am.*, 78, 42-63.
15. Finn, W.D.L, 1991. Geotechnical engineering aspects of seismic microzonation. *Proc. 4th Intern. Conf. Seismic Zonation*, August 25-29, Stanford, California, E.E.R.I. (editor), Oakland CA, I, 199-250.
16. Chavez-Garcia, F.J., M. Rodriguez, E.H. Field & D. Hatzfeld, 1997. Topographic site effects. A comparison of two non-reference methods. *Bull. Seism. Soc. Am.*, 87, 1667-1673.
17. Lebrun, B., D. Hatzfeld & P.-Y. Bard, 1999. Experimental study of ground motion on a large scale topography. *J. of Seismology*, 3(1), 1-15.
18. Boore D. M. (1972). "A note on the effect of simple topography on seismic SH waves", *Bulletin of the Seismological Society of America*, 62: 275-284.
19. Bard, P.-Y. & J.-P. Meneroud, 1987. Modification du signal sismique par la topographie. Cas de la vallée de la Roya (Alpes-Maritimes). *Bull. liaison Laboratoires des Ponts-et-Chaussées*, Numéro special "Risques Naturels" 150-151, 140-151 (*in French*).
20. Neichtschein, S., P.-Y. Bard, J.-C. Gariel, J.-P. Meneroud, P. Dervin, M. Coushing, B. Gaubert, S. Vidal & A.-M. Duval, 1995. A topographic effect study in the Nice region. *Proc. 5th Intern. Conf. on Seismic Zonation*, October 17-19, Nice, France, Ouest Edition Nantes, II, 1067-1074.
21. Chávez-García, F.J. & E. Faccioli, 2000. Complex site effects and building codes: Making the leap. *J. of Seismology*, 4, 23-40.
22. Makra, K., D. Raptakis, F.J. Chávez-García & K. Pitilakis, 2001. Site effects and design provisions: The case of EUROSEISTEST. Pure and Applied Geophysics, Vol.158(12), 2349-2367.
23. Pitilakis, D. (2002) *Numerical and experimental analysis of strong soil motion. Study of site effects in Corseis array and in the town of Aigion.* Diploma Thesis. Civil Engineering Department, Aristotle University of Thessaloniki (in Greek).
24. Ktenidou, O-J. (2003) *Numerical and experimental analysis of strong ground motion - Study of the effect of local soil conditions at CORSEIS array and the city of Aegion, Greece*, Diploma Thesis. Civil Engineering Department, Aristotle University of Thessaloniki (in Greek).