SITE SPECIFIC DESIGN STRONG MOTIONS
AT THE CITY OF VARTHOLOMIO - GREECE

by

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ABSTRACT

For the purpose of studying the effects of local sites conditions on earthquake damage to buildings, a prediction of ground motions at the city of Vartholomio (W. Greece), during the 1988, $M_s=5.9$ catastrophic earthquake is attempted. The expected strong motions were synthesized by means of numerical analysis, employing a 2-dimensional finite difference scheme. A detailed assessment of all the required parameters was performed by employing various geophysical and geotechnical investigations. The results obtained justify the macroseismic observations which can be explained as the combined effect of the presence of low-velocity surface sediments and the topography of the seismic basement.

INTRODUCTION

Site conditions play a major role in establishing the damage potential of incoming seismic waves from major earthquakes. In Greece, there have been recently many consistent macroseismic observations showing that seismic structural damages may be attributed to the soft soil effects on seismic amplification and the shift of the predominant periods to the unfavorable range.

In the present paper, these sorts of effects will be interpreted in view of the constituent soil behavior with due boundary conditions of the site of a magnitude $M_s=5.9$ earthquake which devastated the city of Vartholomio W. Greece Fig.1

FIGURE 1: Epicenter and intensities of the October 16,1988 $M_s=5.9$ earthquake.

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Macroseismic observations in NW Pellopones revealed that seismic intensities reached up to VIII(MM), a value which has been higher than would normally be expected from this particular magnitude and epicentral distance. Also, great differences in structural damage characterized the city of Vartholomio. Since this city, represents a typical Greek city built on top of a soft alluvial basin, it provides us with an opportunity to use it as a pilot city for purposes of seismic microzoning and decisive antiseismic measures.

GEOLOGY OF THE REGION

Vartholomio and its surrounding belong to the external part of the Hellenic Arc which is characterized by intense neotectonic deformation and high seismicity. More specifically, this area is a part of the neotectonic depression (graben) of Pirgos, which is a first order neotectonic structure.

The Alpine formations that crop out to the east and the west of Vartholomio correspond to Gavrovo and Ionian Units respectively. They gradually submerge so as to create an elongated tectonic depression striking N-S. At the city of Vartholomio and its surroundings, the following three categories of geological formations can be located, in geochronological order [2].

-The Vounargos Formation comprising of a large variety of sandstones and shales, having a total thickness of more than 500m. This formation outcrops to the west of Vartholomio and underlies the following two lithological units:

- Calcitic sandstones which locally contain fine or coarser material from various rocks. This unit has a thickness of up to 20m and develops unconformably over the Vounargos formation. It outcrops both west of Vartholomio and at some location within the city.

- Alluvial formations which they develop unconformably over the previous formation and occupy the major plain part of Vartholomio. They consist of clayish sands, sandy clays with an increasing thickness towards the east.

A geological description of the main prevailing lithological units along an E-W cross-section within the city is depicted in Fig.2b, where is compared with the recorded damages Fig.2a. The correlation between the density of damages and the thickness of the alluvial is obvious.

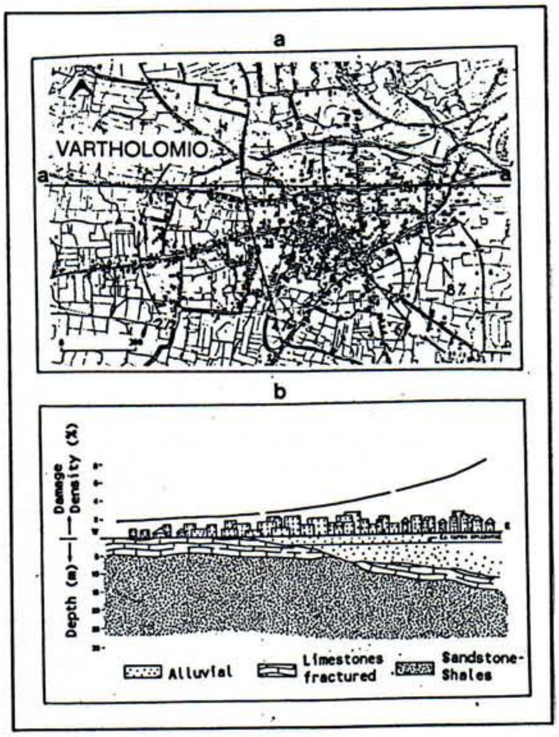

FIGURE 2: Damage distribution (a) and underground structure at the city of Vartholomio (b).

SITE INVESTIGATIONS

The first stage of the research project was devoted towards deriving the geotechnical and other physical properties of the main lithological units along the cross-section depicted in Fig.2 and delineate their distribution versus depth. To achieve this a great suit of state of the art geotechnical and geophysical techniques was applied.

Geotechnical Investigations

Three boreholes were drilled (W1,W2,W3 in Fig.4) at depths of 51.8, 154 and 75.6 m respectively. At all the boreholes we carried out in situ standard penetration tests (S.P.T.) at 1.5m intervals. The soil samples were subjected to classification tests and undisturbed samples tests were also carried out for the determination of the wet bulk density γ.

Furthermore, cross-hole tests were also conducted. The S.P.T. mechanism, rich in shear wave energy was used as a mechanism impulse source. The obtained results are depicted in Fig.3.

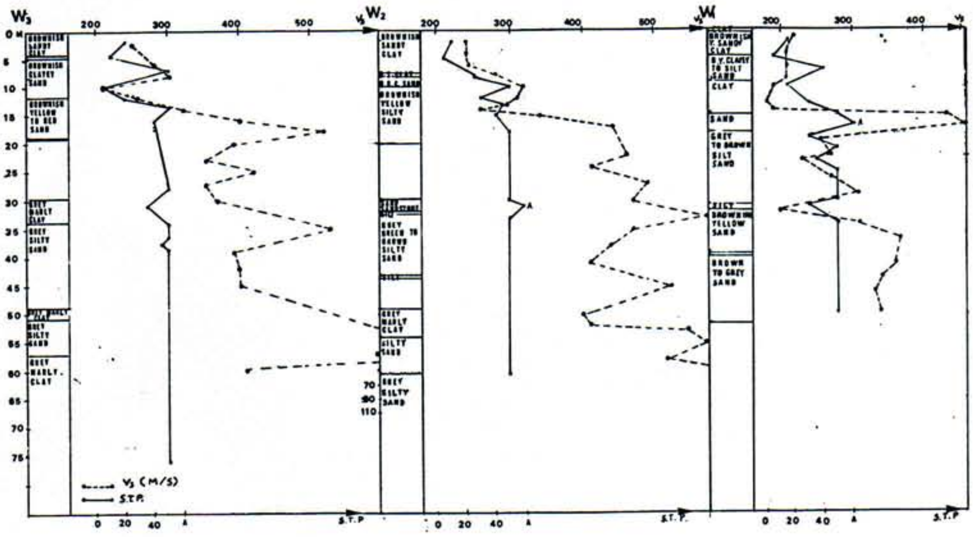

FIGURE 3: Results from geotechnical investigations.

Geophysical Investigations

A Geophysical survey was designed in order to reduce the amount of drill holes needed in order to assess the distribution and dynamic characteristics of the geological formations encountered. In total we contacted 5 Schlumberger geoelectric soundings, 5 overlapped refraction lines with 10m geophone spacings and 3 shallow seismic reflection profiles Fig.4. The seismic instrument used was an ABEM Terraloc signal enhancement 24 channel seismograph and as a seismic source we used a buffalo gun. The combined interpretation of the collected geophysical data resulted in the simplified velocity model of the investigated section, depicted in Fig.5.

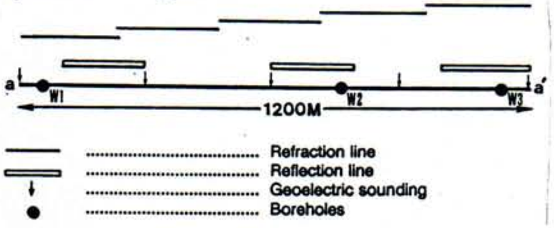

FIGURE 4: Geophysical investigations carried out along section a-a'.

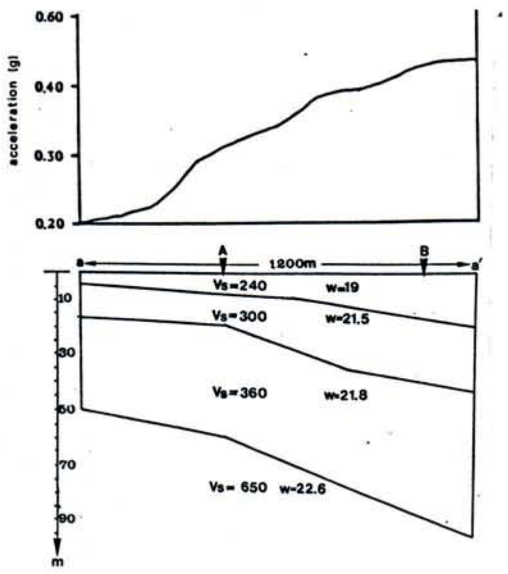

FIGURE 5 : Simplified velocity model of the investigated area. Vs = shear wave velocity in m/s, W is specific weight in KN/m^3. Superimposed are also depicted the calculated surface accelerations. Vectors indicate locations where response spectra were derived.

A major section of the geophysical investigations was devoted in the problem of assessing the dynamic elastic properties of the main lithologic units encountered. To do this we carried out cross-hole investigations at the three exploration wells W1,W2 and W3 Fig.3. Also the parameters of the geological formations between the above wells were derived by applying the following technique.

By dropping a 1/2 tone weight, we generated Rayleigh waves which were recorded on 12 channels. Next, the corresponding dispersion curve was evaluated and was inverted by employing a new developed algorithm [4], resulting in the variation of shear modulus and shear wave velocity versus depth Fig.6.

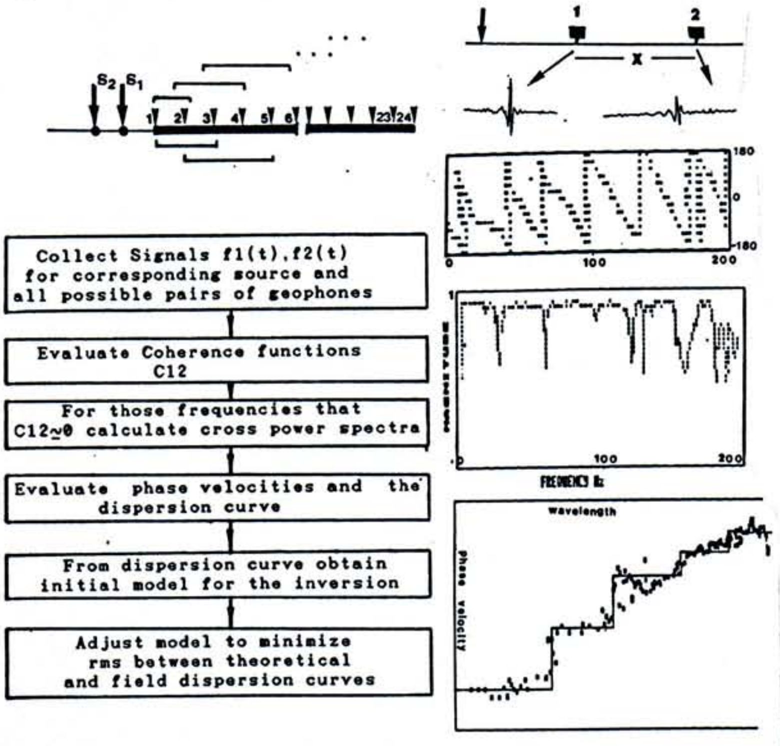

FIGURE 6: Evaluation of shear wave velocity and shear modulus for the inversion of the dispersion characteristics of artificially generated Rayleigh waves.

EVALUATION OF INPUT MOTION

At Vartholomio, a region which experienced the heaviest damages during the event, ground acceleration was not recorded. On the other hand records of ground acceleration were obtained Fig.7 at a distance of about 20Km to the SE at the nearby city of Amaliada Fig.1. We used these recordings to synthesize the motion at Vartholomio in the following way.

First, the input ground motion at the seismic basement at Amaliada station was evaluated by SHAKE deconvolution and then was transferred to Vartholomio site by employing the following formula

$$a(t)=\frac{1}{2\pi}\int A_r(\omega)e^{-\frac{\pi f\Delta R}{QV_s}}e^{i\omega t}d\omega \qquad (1)$$

where $A_r(\omega)$ is the Fourier spectra of the deconvolved recording at Amaliada site, ΔR the difference in epicentral distance between the two sites, V_s the shear wave velocity and Q the quality factor. Assuming a representative value of Q=220 for the region [5] and a shear wave velocity of V_s=3.4Km/s the synthesized input motion at Vartholomio was derived.

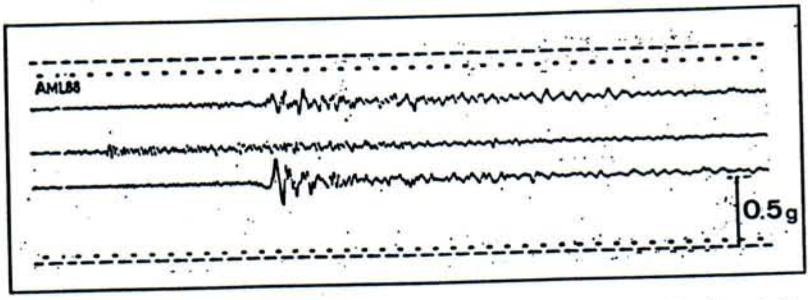

FIGURE 7: Strong motion records obtained at Amaliada station.

EVALUATION OF SEISMIC MOTIONS AT THE SURFACE

In order to derive the wave field at the surface, we employ a finite difference method with the 2-D model depicted in Fig.5. The following basic equation of motion for SH waves is used

$$\frac{\partial}{\partial x}(\mu\frac{\partial u}{\partial x})+\frac{\partial}{\partial z}(\mu\frac{\partial u}{\partial z})=\rho\frac{\partial^2 u}{\partial t^2} \qquad (2)$$

where u(x,z) is the displacement, ρ(x,z) the density, t the time and μ(x,z) the shear modulus. The numerical solution of eq.1 is realized by a conservative 2nd order finite difference scheme [6] employing a regular in space finite difference grid with constant step Δx=Δz, and constant time increment Δt. The displacement at t=(k+1)Δt is determined from the displacement at the two preceding levels kΔt and (k-1)Δt:

$$\begin{aligned} u_{I,J}^{K+1}=2u_{I,J}^{K}-u_{I,J}^{K-1}+\left(\frac{\Delta t}{\Delta x}\right)^2\frac{1}{\rho_{I,J}}[\mu_{I,J}^{H}u_{I,J+1}^{K}- \\ -(\mu_{I,J}^{H}+\mu_{I,J-1}^{H})u_{I,J}^{K}+\mu_{I,J-1}^{H}u_{I,J-1}^{K}+\mu_{I,J}^{V}u_{I+1,J}^{K}- \\ -(\mu_{I,J}^{V}+\mu_{I+1,J}^{V})u_{I,J}^{K}+\mu_{I-1,J}^{V}u_{I-1,J}^{K}] \end{aligned} \qquad (3)$$

Indices I and J are for the space discretization in the z and x coordinates. MI,JV and MI,JH represent the shear wave velocities squared. At the edges of the computation region the non-reflecting boundaries are introduced according to [3]. In the first step of the calculations we compute an approximation to the impulse response of the 2-dimensional model of the region by exciting it with a simple delta-like impulse of short duration. As excitation signal we used a unipolar (one-sided) Ricker wavelet, whose zero frequency value is unity. Furthermore, absorption correction were implemented, based on a frequency independent Q model [1]. Fig.8 depicts in detail the calculation procedure followed in order to obtain the surface accelerations.

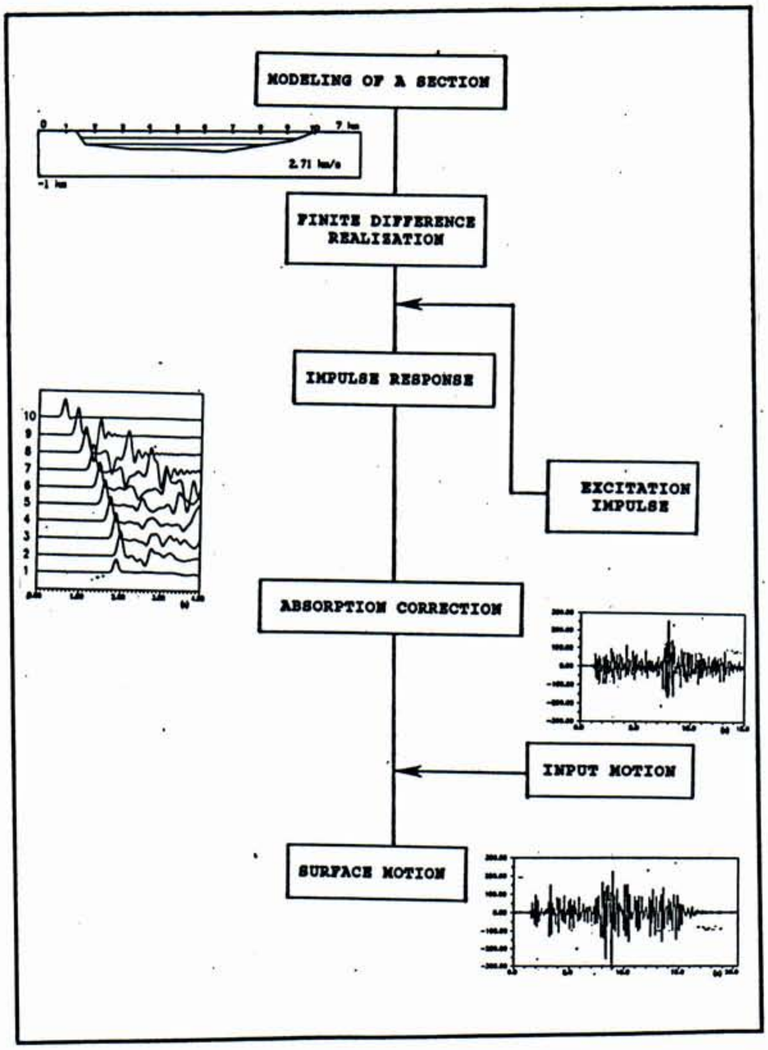

FIGURE 8: Numerical synthesis of strong motion at surface.

DISCUSSION OF THE RESULTS

In Fig.2 we depicted the distribution of damages observed at the city of Vartholomio. From the 1153 buildings examined, the 173 experienced severe structural damage and had to be demolished, while 770 buildings suffered major structural damage and had to be repaired before reoccupation.

Fig.5 shows the calculated surface accelerations superimposed on a simplified model of the region. The gradual increase of the accelerations from a value of 0.21g in the west towards a value of 0.42g towards the east is obvious and this is in agreement with the obtained macroseismic data. Furthermore, response spectra evaluated at the right end of the section investigated indicate a maximum value of 0.46g Fig.9.

CONCLUSIONS

In the present research, we tried to predict the expected ground motions at a site in Western Greece and compare the analytical results with macroseismic observations. The calculations were based on a detailed geological model obtained after a combination of 3 different geophysical techniques while the required elastic parameters were obtained from geophysical, and geotechnical surveys. The results showed a very good correlation with the macroseismic data and indicate that in certain cases it may be possible to assess the expected ground motion at a site if we take into account the local site conditions.

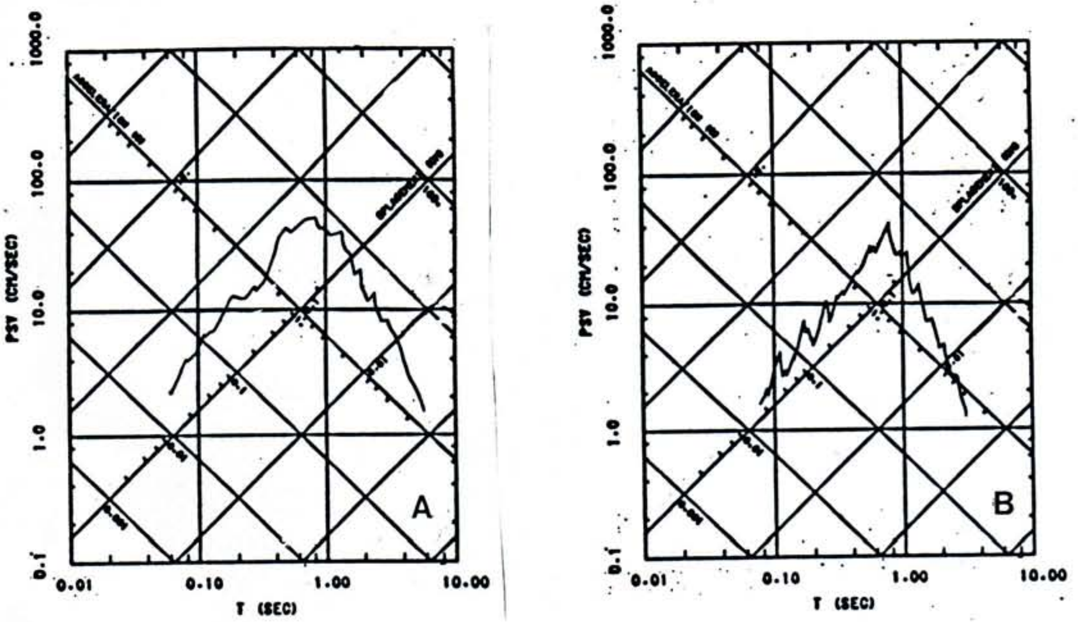

FIGURE 9: Response spectra evaluated at the right end of section a-a'.

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