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# Site Dependent Ground Response for the City of Patras, Greece

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# Site Dependent Ground Response for the City of Patras, Greece

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**SYNOPSIS** Results of a preliminary study of seismic ground response at different sites of the coastal city of Patras, in Southern Greece, are presented. At each site equivalent linear 1-D response analyses were conducted by using the finite element program LUSH 2. Values of dynamic properties of soils were obtained from either cross-hole tests or empirical correlations. The "rigid base" excitation was selected as to best simulate the expected bedrock motions in Patras from local and distant earthquakes. The results of the analyses indicate a strong differentiation of seismic site response when moving from the coastal region of the city to the inland area. Peak surface accelerations were found to vary from 0.10 g in the coastal region to 0.50 g in the inland area, whereas the corresponding values of spectral acceleration ranged from 0.30 g to 2.0 g. Strong motion records obtained in the city during the July 14, 1993 $M_s$ = 5.4 Patras earthquake are in agreement with the results of this study. It is concluded that a systematic microzonation study of Patras would contribute to the seismic protection of the city.

## INTRODUCTION

The coastal city of Patras in Southern Greece, Fig. 1, is the third largest city in the country (population ≈ 155 000) and, due to its geographic position, its port is considered as the gate of the country to the West. The city, known since historic times, is located in the vicinity of the most seismically active region of Europe and is surrounded (and even crossed!) by active faults that have the potential of generating strong earthquakes.

The city is underlain by plio-pleistocene sediments exhibiting two major horizons: the fine-grained lower horizon has the greater thickness and consists of gray marls, silty clays and sandy silts whereas the upper coarse-grained horizon consists of alternating layers of clays, sands, gravels, conglomerates and clayey silts. In the coastal zone of the city the plio-pleistocene sediments are covered by younger quaternary and recent deposits whereas in some of the inland hilly regions these sediments are exposed at the ground surface. The basement rocks (which outcrop in the mountainous area eastward to south-eastward of the city) consist mainly of flysch formations and of thin-bedded limestones and radiolarites and they are believed to lie at a depth greater than 300 m (Kalteziotis et al., 1991).

Due to the extensional stresses acting in the area since the period of upper Neogene two groups of normal faults have developed in the plio-pleistocene sediments with mean strikes in the NE - SW and NW-SE directions (Kalteziotis et al., 1991). The high seismicity of the area is believed to be closely related to the aforementioned fault system and actually one of the NE-SW branches crossing the southern part of the city has resulted in damage to buildings in the period of 1989-1990 (Kalteziotis et al., 1991). The seismic history of the region reveals that Patras can be affected by distant earthquakes (epicentral distances greater than 150 km) in addition to local and intermediate distance earthquakes. Finally, the effects of local soil conditions on the surface motion have to be taken into account to properly design earthquake resistant structures (Finn, 1992).

In this paper the results are presented of a preliminary study of the effects of site conditions on the seismic ground motion in the city of Patras. It is shown that the differentiation of soil profiles in different areas of the city can generate significant differentiation of the surface motion. These findings were veryfied by the strong motion records obtained in two different (from the point of view of soil conditions) sites of the city during the July 14, 1993 Patras earthquake.

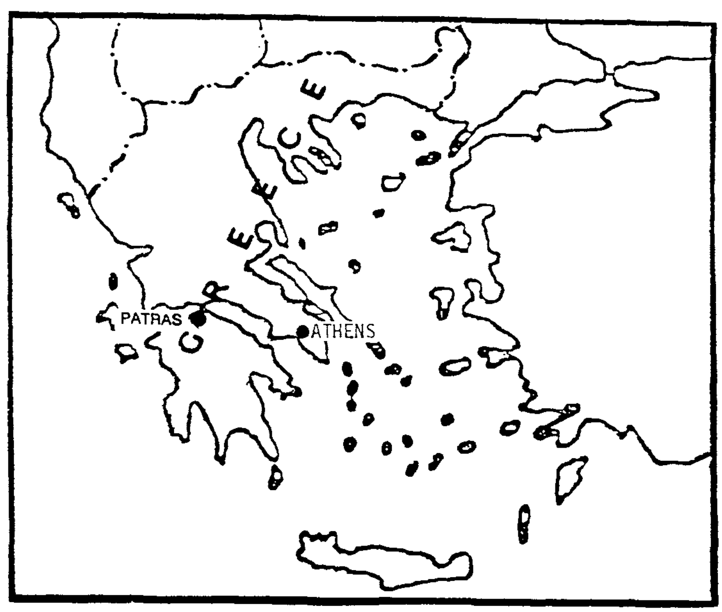


Fig. 1. Geographic Location of the City of Patras

## GEOTECHNICAL DATA

Data for the soil formations underlying Patras were obtained in this study from the files of a number of geotechnical investigations carried out by privately owned firms and govermental organizations. These investigations had included borings up to 60 m from ground surface, in-situ tests (SPT or CPT) and laboratory tests of strength and compressibility. For few sites data from Cross-hole tests, conducted by the author or other agencies, were also available. It is worth to be mentioned that although the sites examined in this study were selected with the sole criterion of availability of geotechnical data from previous investigations, the distribution of sites was such that covered a variety of soil profiles encountered in the area of the city.

Fig. 2 shows a map of Patras with the position of about 20 sites for which geotechnical data were obtained. The soil profile at SITE 1, shown in Fig. 3, is typical for the coastal zone of the city. It is characterized by the presence of a thick layer of very soft gray colored clay of low plasticity at a depth of about 10 m. The water table is very high in this zone of the city -one to two meters from ground surface. When moving away from the coastline the soil profile changes gradually and the clay layer becomes stiffer. A soil profile of this type is found in

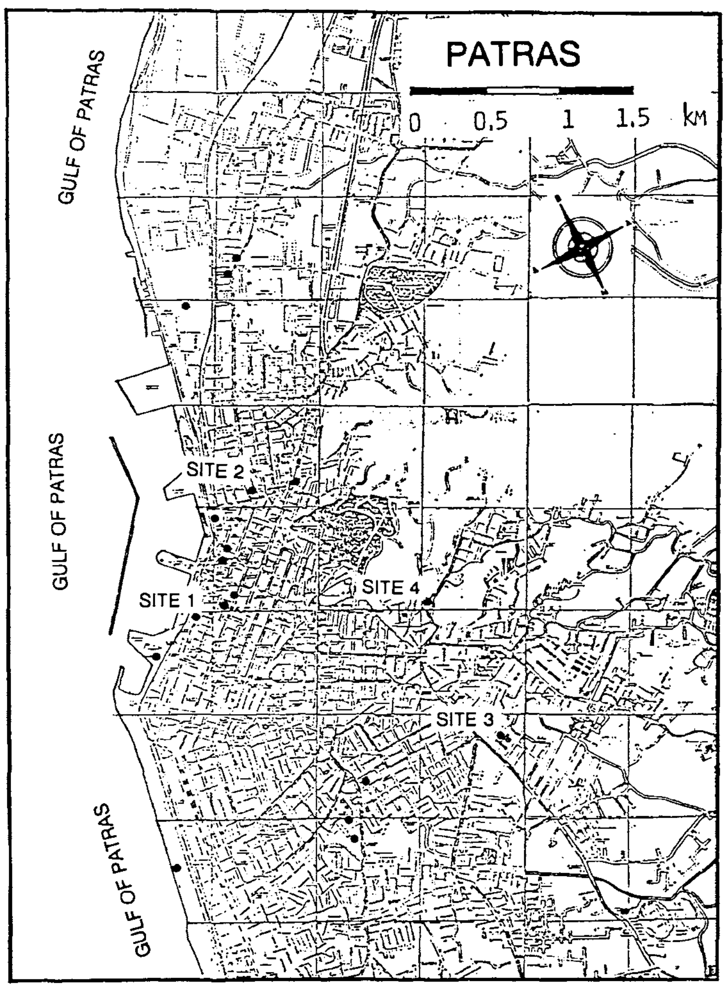


Fig. 2. Map of Patras With Locations Where Geotechnical Data Were Available From Previous Investigations

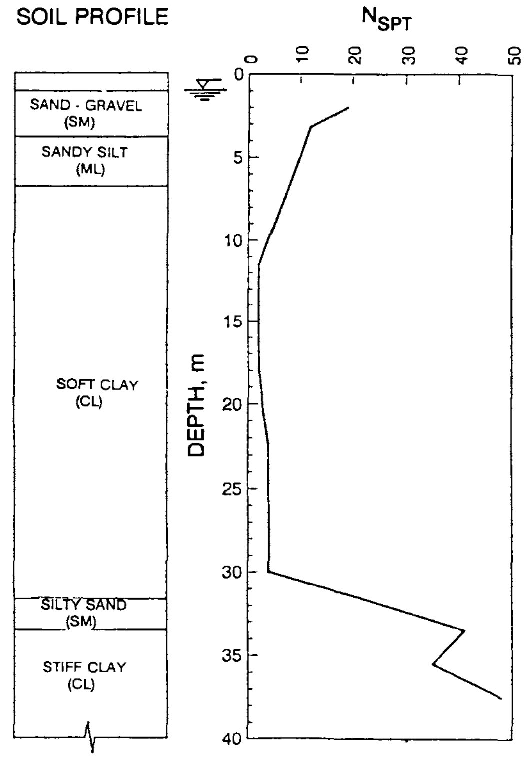


Fig. 3 Soil Profile at Site 1

SITE 2, shown in Fig. 4. The depth to water table is also increased in this site (6.5 m from ground surface) and values of shear wave velocity were available from Cross-hole measurements conducted by the author. Moving farther away from the coastal zone the soil profiles involve clay layers of greater stiffness and the depth to water table is greater than 20 m. The soil profile of SITE 3 depicted in Fig. 5 is an example of this type of profile. It should be mentioned that some of the very high values of $N_{SPT}$ shown in the diagram of Fig. 5 are extrapolated values estimated by the author based on the results of partial penetration of the Terzaghi sampler. Finally, the hilly terrain encountered in the eastern part of the city is characterized by soil profiles consisting of a surface layer of brownish clay of low plasticity, having a thickness ranging from 9 m to 12 m and underlain by a gray colored clay of low plasticity. Fig. 6 depicts a soil profile of this type (SITE 4). The water table is deep in these sites, however, perched water tables are found in depths ranging from 3.5 m to 20 m in this type of profiles.

## SEISMIC RESPONSE ANALYSES

Soil response analyses at each site were conducted by using the finite element program LUSH 2 in one dimensional mode (Lysmer et al., 1974), Fig. 7. This program implements on iterative procedure to achieve compatibility between values of soil shear modulus and corresponding shear strains i.e. it utilizes an equivalent-linear behavior for soil materials. As was mentioned in the previous section at only few sites were available values of shear wave velocity, $V_{so}$, vs. depth from Cross-hole tests. For the rest of the sites the followning empirical correlation, developed recently by the author, was used for estimating

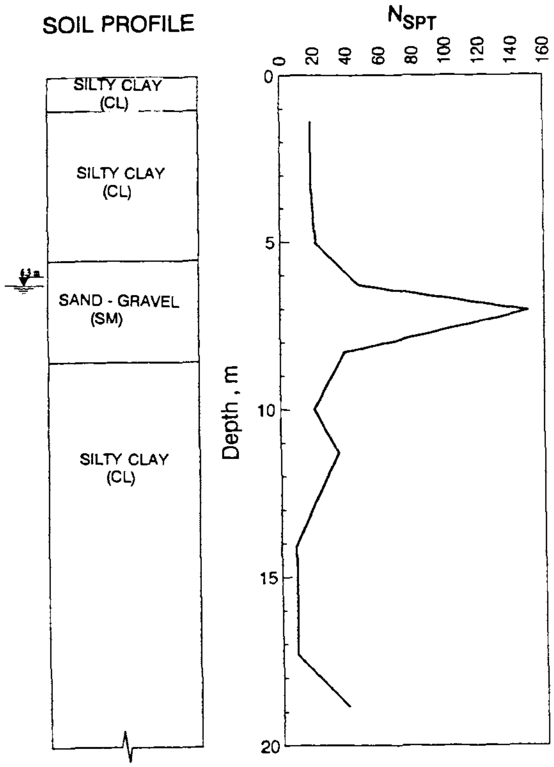


Fig. 4. Soil Profile at Site 2

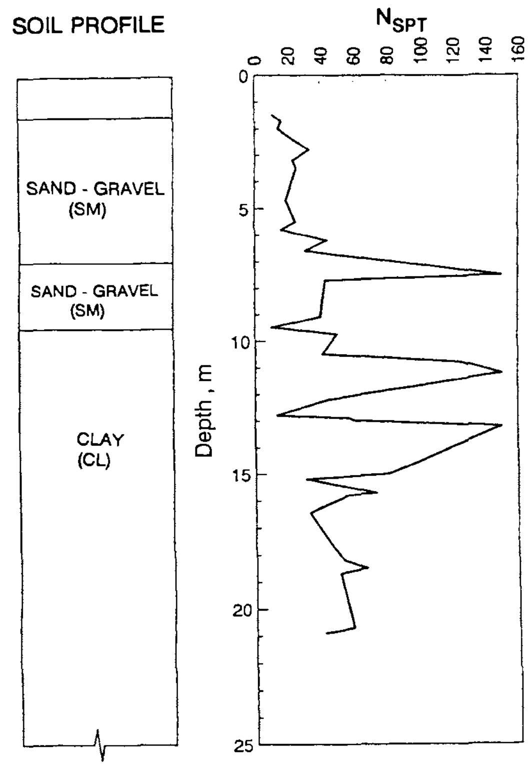


Fig. 5. Soil Profile at Site 3

values of $V_{so}$ from the blow count of Standard Penetration Test, $N_{SPT}$:

$$V_{so}(m/sec) = 107.6(N_{SPT})^{0.36} \quad (1)$$

Values of $V_{so}$ predicted by Eq. 1 have been found to deviate by ± 30%, on the average, from values measured by Cross-hole testing (Athanasopoulos, 1994).

The rigid base at each site was defined by the criterion $V_{so} \geq 750$ m/sec. In only few of the sites, this criterion was met within the limits of investigated depth. In most of the cases an extrapolation of $V_{so}$ values to greater depths - taking into consideration the general trend - became necessary. Due to lack of site-specific data for modulus degradation and damping ratio curves, it was decided to use the curves shown in Fig. 8 for all types of soil.

The rigid base excitation for the response analyses was provided in the form of the two acceleration time histories shown in Fig. 9. These are considered to correspond to two earthquakes with the followning characteristics: **Earthquake I** has a magnitude M = 6 and epicentral distance less than 10 km. According to attenuation data reported by Theodoulidis and Papazachos (1992), the base motion of this earthquake could be characterized by peak rock acceleration $a_r$ = 0.30 g and a predominant period of vibration $T_p \approx 0.20$ sec. The pertinent characteristics of **Earthquake II** are: M ≥ 6.5, epicentral distance greater than 50 km and $a_r$ = 0.19 g, $T_p \approx 0.4$ sec. It is recognized that in order to complete the study of soil seismic response for Patras, a third earthquake with M = 7.5 and epicentral distance greater than 100 km should also be considered. Some preliminary results on this subject are already available but they will not be included in this paper.

The results of the response analysis for each site included the variation of peak values of acceleration, effective shear strain and shear stress with depth as well as the spectral accelerations and velocities at the ground surface.

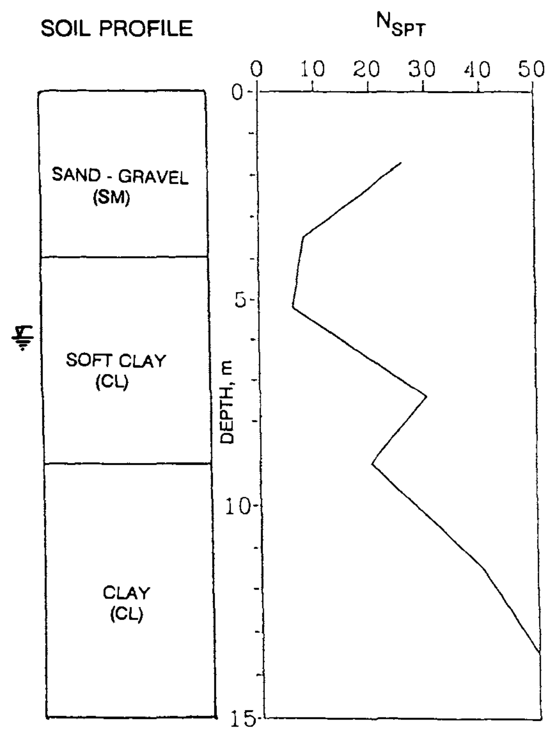


Fig. 6. Soil Profile at Site 4

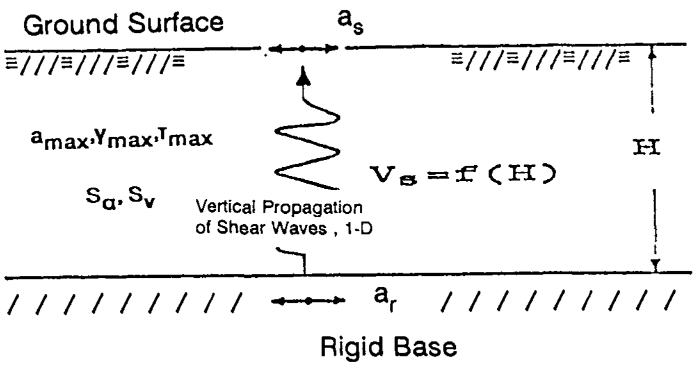


Fig. 7. One-dimensional Soil Response Analysis

## RESULTS OF ANALYSES AND DISCUSSION

Results of response analyses for the four sites examined in the previous section and for **Earthquake I** are presented in graphical form in Fig. 10 through Fig. 13. It is observed that in SITE I the surface acceleration is less than 0.10 g and the corresponding peak value of spectral acceleration is lower than 0.20 g at a predominant period of 1.4 sec, Fig. 10. It is believed that these low values of response are due to the presence of the thick layer of very soft clay. However, for a distant earthquake the response in this area of the city may be particularly intense. For **Earthquake II** the corresponding value of peak surface acceleration is 0.12 g and of peak spectral acceleration 0.50 g.

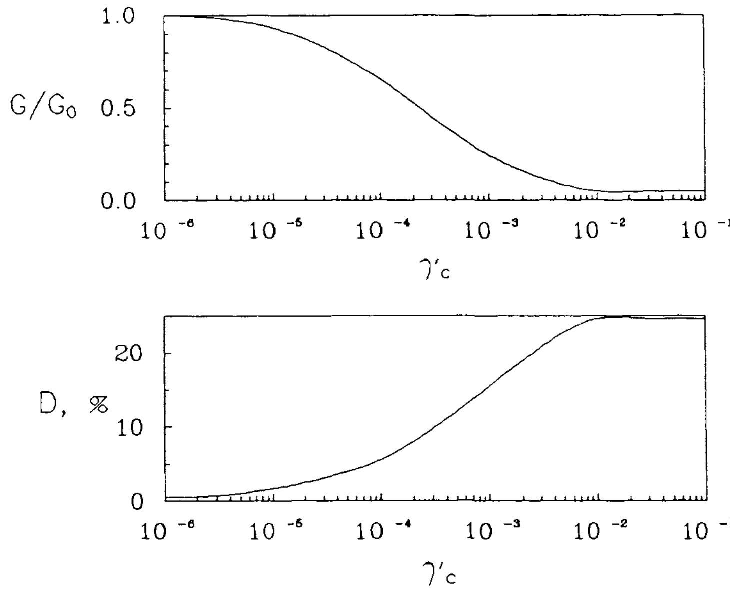


Fig. 8. Modulus Degradation and Damping Ratio Curves Used in the Response Analyses

The results for SITE 2 are shown in Fig. 11 in which may be observed the gradual increase in the response values as one moves away from the coast. The peak surface acceleration is increased to 0.28 g whereas the spectral value becomes 0.9 g at a predominant period of 1.4 sec.

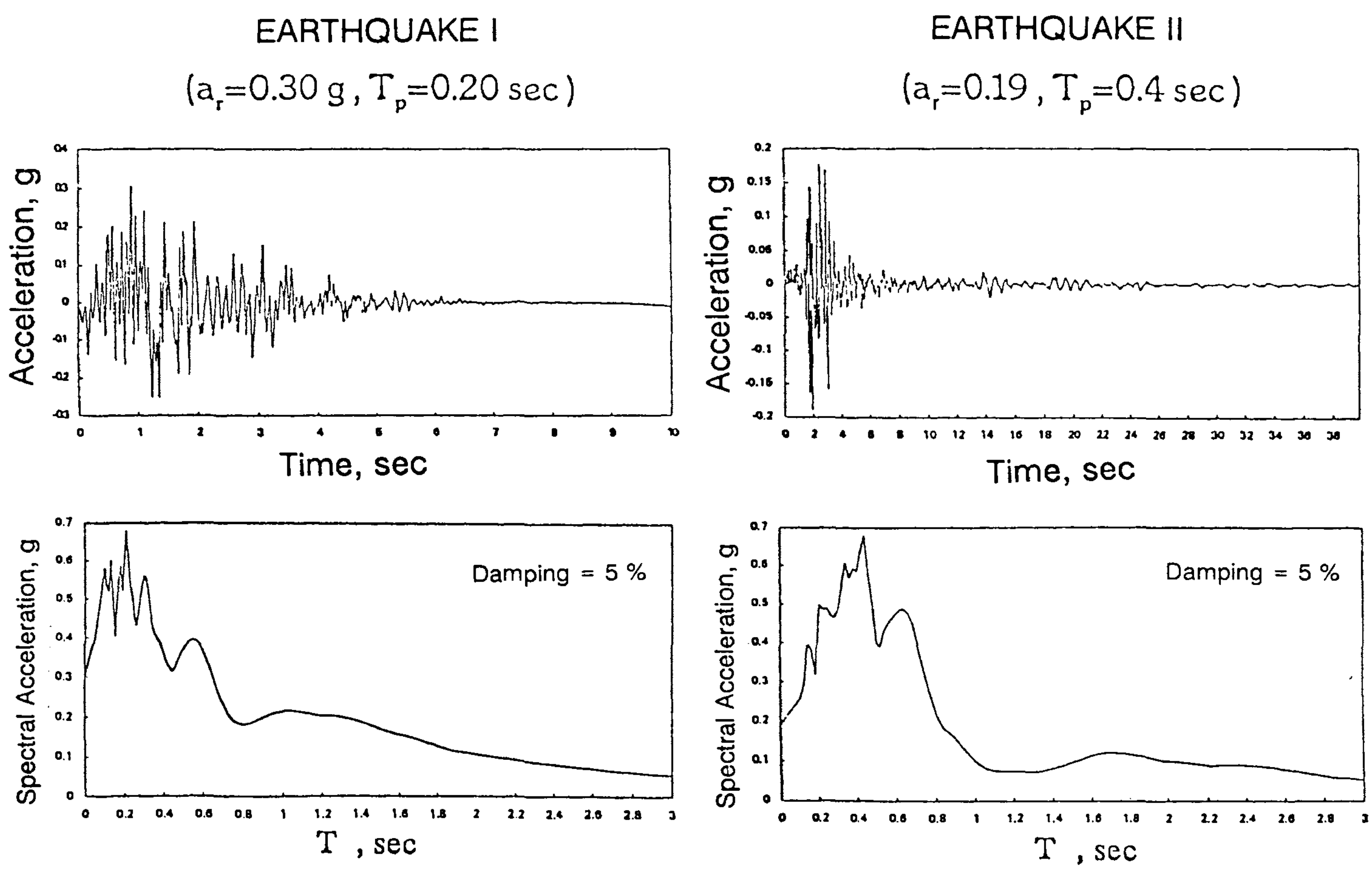


Fig. 9. Acceleration Time Histories Used in the Analyses

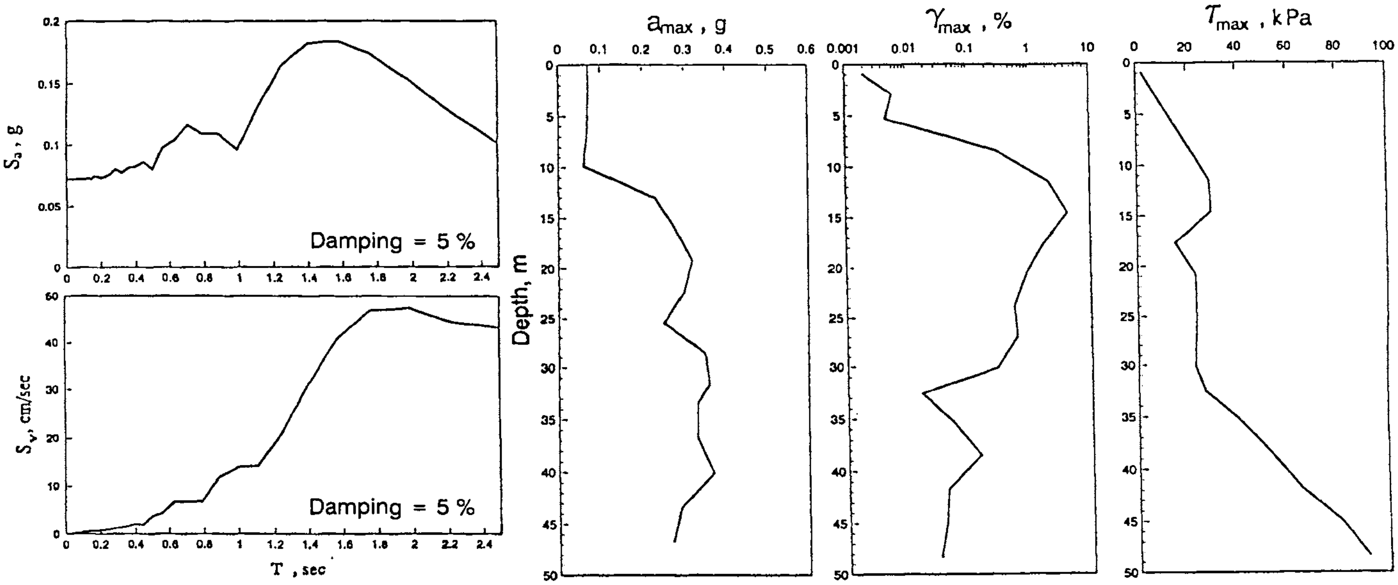


Fig. 10. Results of Response Analyses for SITE 1

For **Earthquake II** the corresponding values are: 0.25 g, 1.40 g and 1.4 sec.

The much stiffer soil profile of SITE 3 increases further the intensity of response as shown in the diagrams of Fig. 12. The peak surface acceleration becomes equal to 0.38 g and the peak spectral value equal to 1.4 g at a predominant period of about 0.2 sec. The response increases further for **Earthquake II**: peak surface acceleration = 0.45 g and peak spectral acceleration ≥ 2 g at a predominant period of 0.6 sec.

Finally, for SITE 4, representative of the eastern portions of the city, the results shown in Fig. 13 indicate particularly intense ground motion. The peak surface acceleration approaches the value of 0.50 g and the corresponding spectral value is equal to 1.60 g at a predominant period of 0.5 sec. The corresponding values for **Earthquake II** are: 0.50 g, 2.30 g, and 0.65 sec. It should be mentioned that in this portion of the city some modification of surface motion is also expected due to the effects of surface topography.

The distribution of peak surface accelerations for **Earthquake I** along the area of the city is shown in Fig. 14. The trend of increasing values when moving away from the coast - at least in the central portion of the city - may be observed in this map. The picture does not change significantly when the results for **Earthquake II** are plotted on the map. Some preliminary results for a distant earthquake, though, indicate a

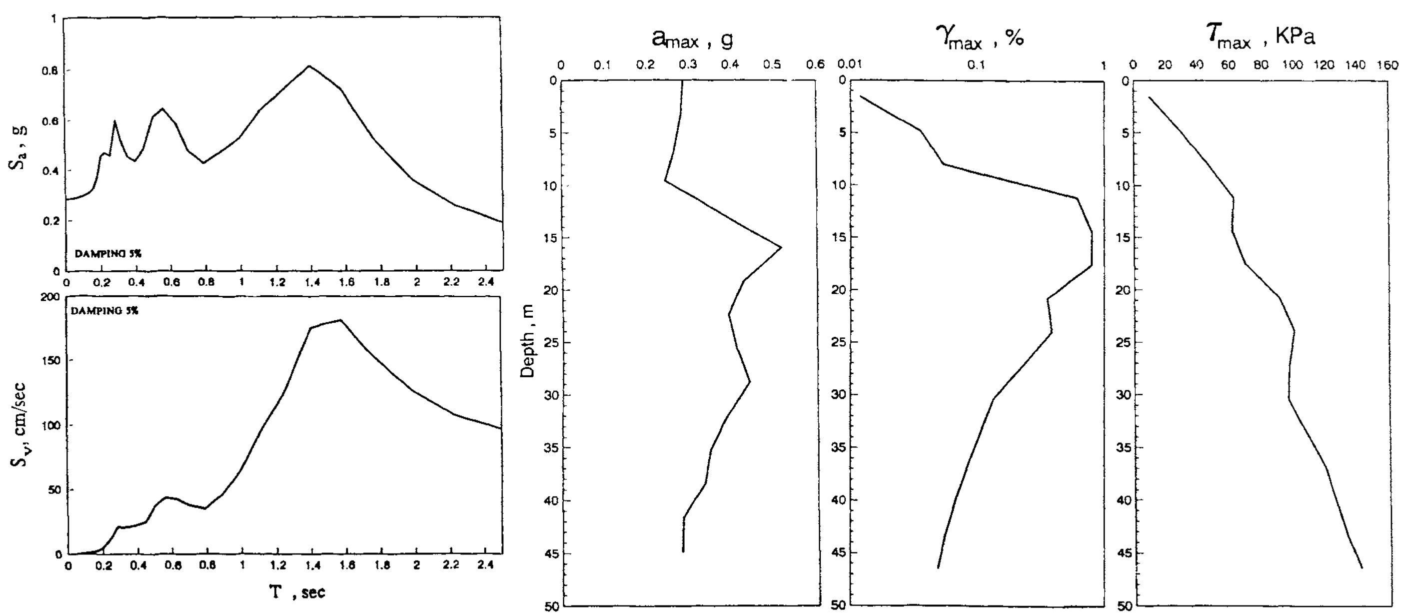


Fig. 11. Results of Response Analyses for SITE 2

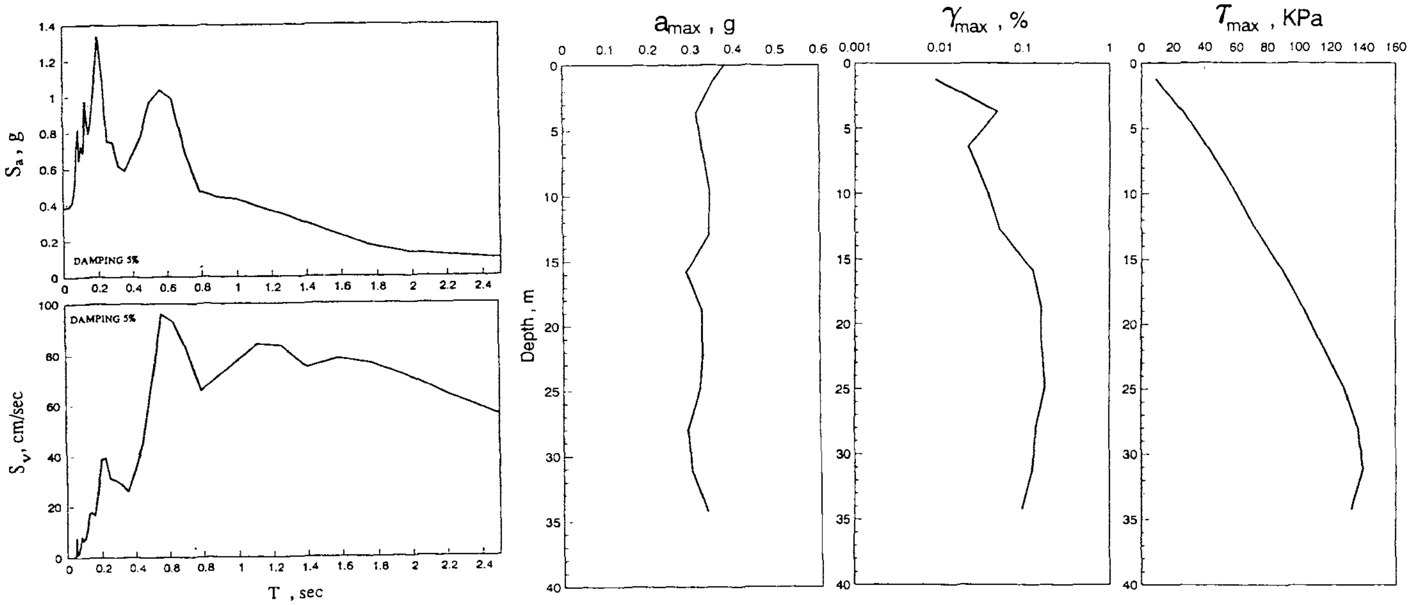


Fig. 12. Results of Response Analyses for SITE 3

drastic change of response in the coastal zone of the city. In the map of Fig. 15 an attempt is made to divide the area of the city into three zones according to the intensity of expected peak surface accelerations. This zonation applies to the case of a strong local earthquake and it will be changed for the case of a strong distant earthquake.

It is worth mentioning that two strong motion records were obtained in the city of Patras during a local earthquake with magnitude $M_s$ = 5.4, which occured on July 14, 1993. The records were obtained at two sites with different soil conditions, shown in the map of Fig. 16, and became available after the results of the present study were obtained (ITSAK, 1993). According to the published information STATION 2 underlain by stiff soil layers, recorded peak accelerations of about 0.42 g, whereas STATION 1, underlain by less stiff soils, recorded peak accelerations of only 0.21 g. These recordings are in agreement with the findings of the present study and a comparison of the map of Fig. 16 to the map of Fig. 15 shows that STATION 1 falls into ZONE 2 whereas STATION 2 falls into ZONE 3.

## CONCLUSIONS

A preliminary study for the effects of soil conditions on the seismic soil response in the city of Patras, Greece was conducted. Data for the soil conditions of the city were obtained from the files of geotechnical investigations carried out for the design of various structures in the city. The results of the analyses indicate that the differentiation of soil conditions may result in significant differentiation of motion in terms of both intensity and frequency content. Strong motion records obtained for an $M_s$ = 5.4 shock that occured on July 14, 1993 in Patras, are in agreement with the results of this study. A tentative zonation of the city

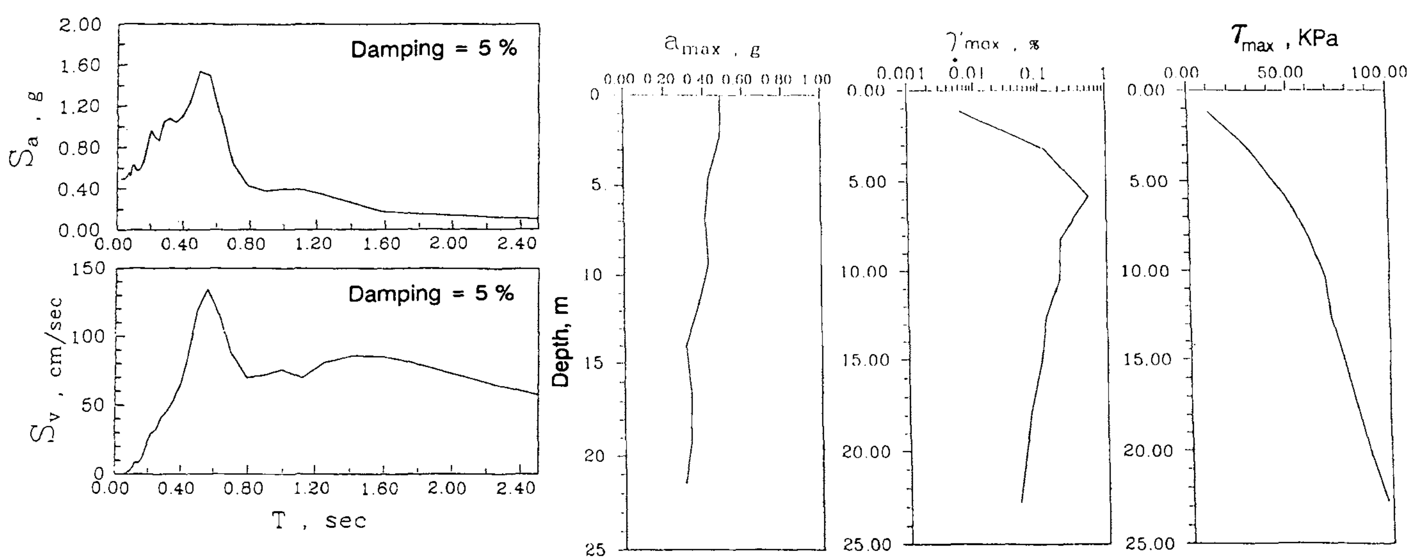


Fig. 13. Results of Response Analyses for SITE 4

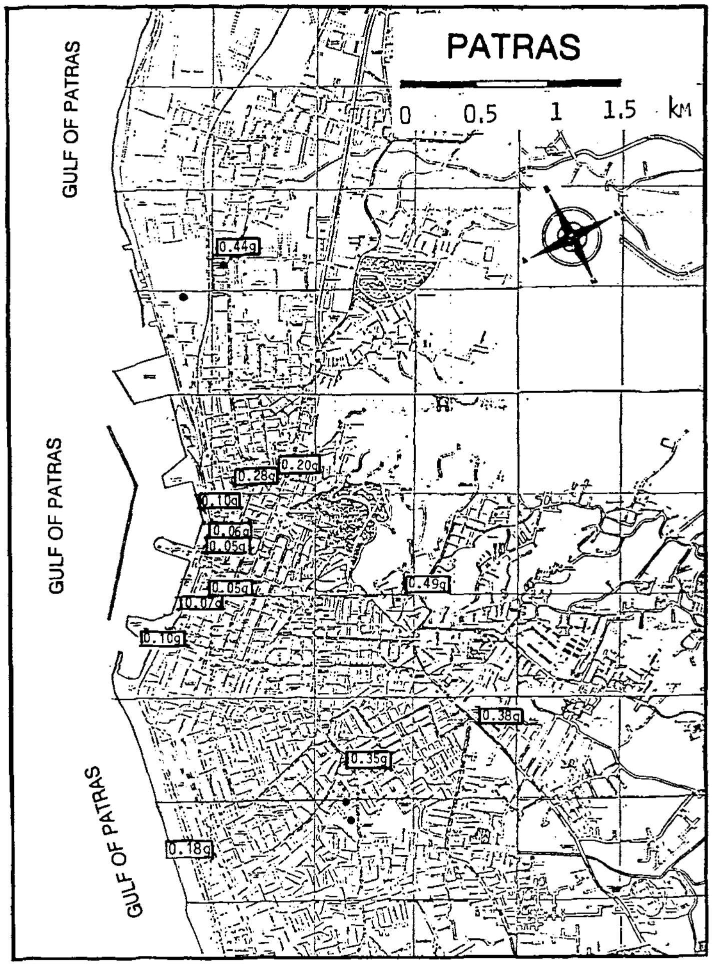


Fig. 14. Distribution of Peak Surface Accelerations for Earthquake I

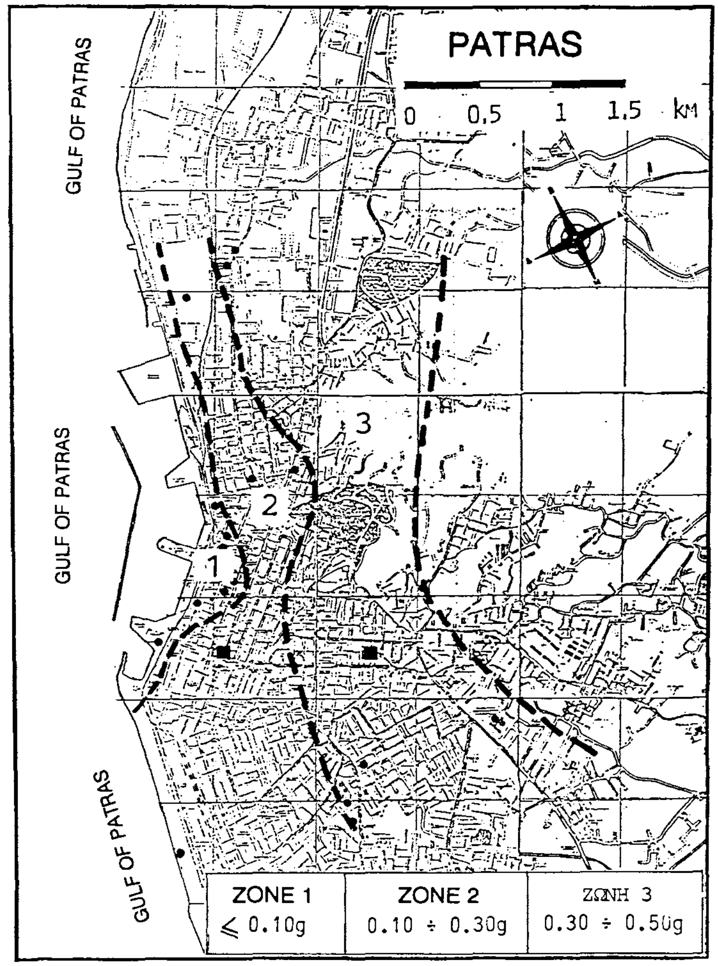


Fig. 15. Preliminary Zonation of Patras Indicating the Expected Peak Surface Accelarations From Earthquake I and II

is proposed for the case of strong local and small epicentral distance earthquakes. It is believed that the execution of a systematic microzonation study of the city would contribute significantly to the planning of earthquake protection measures for the existing and new structures in the area as well as to possible adaptations to the New Hellenic Seismic Code (1992).

## ACKNOWLEDGEMENTS

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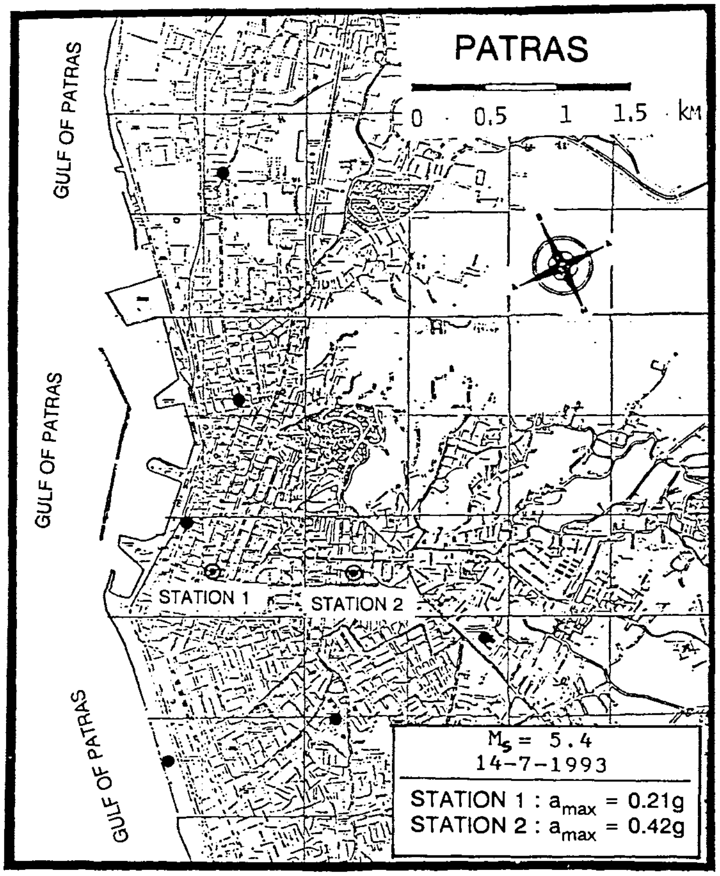


Fig. 16. Location of the Two Stations at Which Strong Motion Records of the Patras 07/14/1993 Earthquake Were Obtained

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